Rothamsted Experimental Station
Harpenden

LAWES AGRICULTURAL TRUST

REPORT

for

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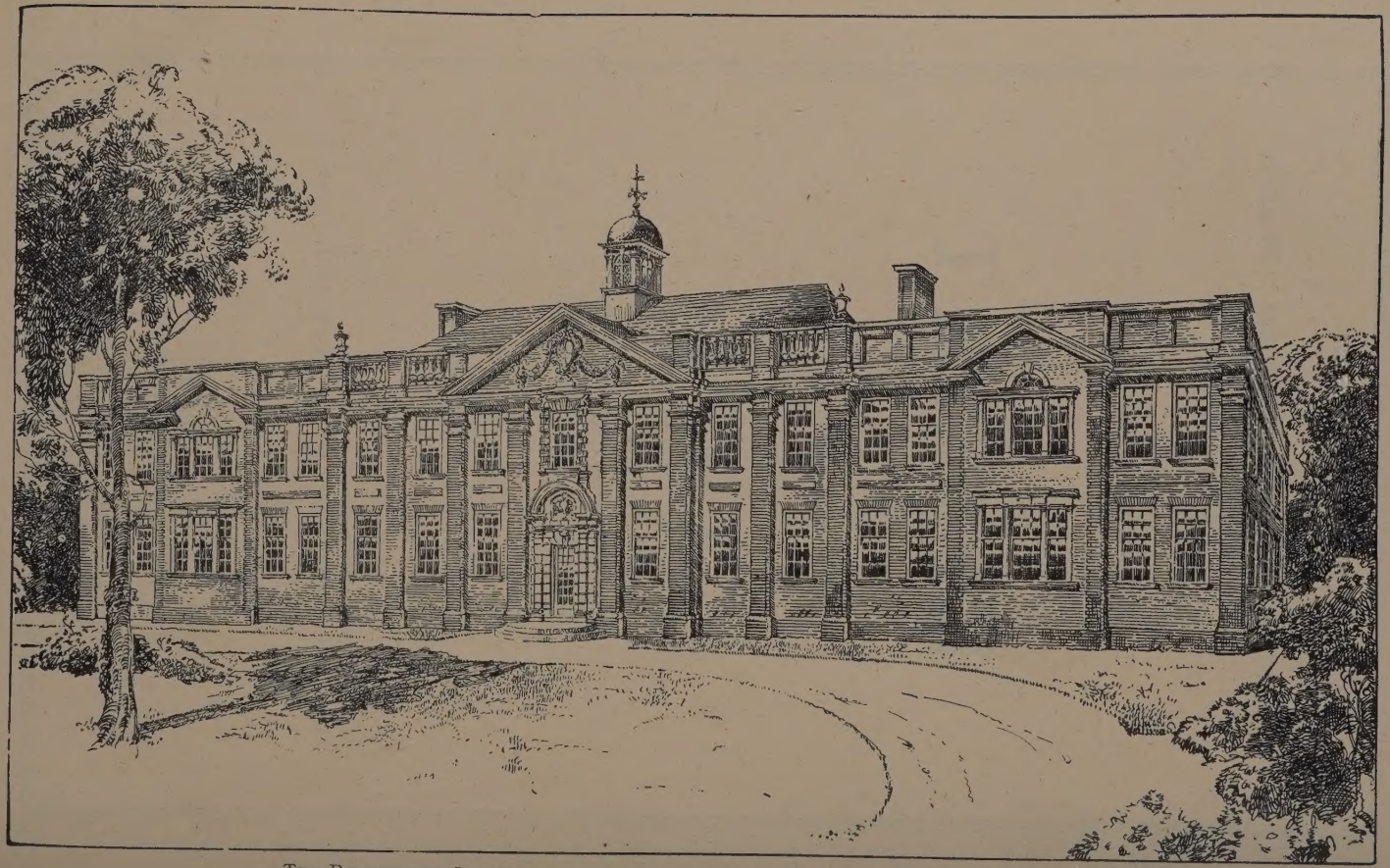

THE ROTHAMSTED LABORATORIES FOR SOIL AND PLANT NUTRITION, ERECTED 1914-1915.

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The purpose of the Society is to collect funds for continuing and extending the work of the Rothamsted Station.

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F. C. Bawden, M.A., F.R.S. (Plant Pathology Division)

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Bee Department

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Assistant Staff	J. C. Adams, A. J. Brace, J. B. Clifford, N. Ellement, Marion Nunn, Joan Saunders, Joyce White, F. E. Woodstock

Field Experiments Section

Head of Section	H. V. Garner, M.A., B.Sc.
Staff	M. J. Allen Myrtle Hughes (Clerical assist.) Kathleen J. Skidmore, N.D.D. B. Weston (Field Superintendent)

Farm Staff

Farm Manager	J. R. Moffatt, B.Sc.(Agric.), N.D.A., A.I.B.A.E.
Assistants to Farm Manager	G. F. Cole, C. R. L. Scowen
Secretary	Pauline Cope
Typist	Ann S. Fakes
Recorders	J. M. Bidgood, F. V. Cooper, B.Sc. (Agric.)
Foreman	H. P. Currant
Farm Workers	T. E. Ablewhite, A. Atkinson, J. Bird, P. Bird, D. Burks, W. A. H. Burton, W. Cain, H. S. Chapman, P. W. Currant, A. Jennings, A. Mills, F. Stevens, F. Stokes, J. Underhill, H. A. Walford, F. E. S. West

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Assistant Librarian ..	K. Toni Sumner
Assistants	Audrey Saunders, Sheila Webb

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Shorthand Typist	Anna Vincenzi
Assistant to Secretary (part-time)	Constance K. Catton
Senior Assistants	Mrs. S. Coleman Mildred E. Ashford
Clerks	Mrs. D. Coates, Joan Gardner, Mrs. R. Pepper, Mrs. D. Price, Beryl Thorne, Anne Walker,

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Photographer	V. Stansfield, F.R.P.S.
Draughtswoman	Audrey I. Simpson

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Assistants	Mrs. K. M. Kirkwood, Mrs. F. Watson, Mrs. A. Speyer

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Caretakers, Cleaners, Gardeners, etc.	L. Allen, B. G. Burgess, W. S. Fisher, Mrs. Hamilton, F. Hamilton, F. K. Hawkins, G. E. Hooper, T. Jackson, F. J. Kilroy, H. Moody, E. Needham, R. C. Parrott, Mrs. Parrott, W. K. Smith, Mrs. Smith, A. P. Snowling, F. J. Stock, H. A. Weston

Members of the Scientific Staff who left between January and December, 1951

Biochemistry Department	D. Miller, B.Sc.(Agric.) G. Parker, B.Sc., Ph.D.
Chemistry Department	A. H. Green, B.Sc. J. B. Rickson, B.Sc., A.R.I.C.
Entomology Department	G. Owen Evans, M.Sc., Ph.D.
Physics Department	W. C. A. Hutchinson, B.Sc.
Soil Microbiology Department	Janet E. Brind, Ph.D. Miss Ada McCallum, B.Sc.
Soil Survey of England and Wales	D. F. Ball, M.A. I. L. Freeman, B.Sc. W. A. Mitchell, B.Sc.
Statistics Department	G. Jolly, B.Sc. Rowena Lord, B.Sc.

We regret to report the death, in November, 1951, of Mr. J. W. Weil, M.A. of the Field Experiments Section.

The following spent varying periods as temporary workers at Rothamsted during 1951

Australia: S. M. Bromfield (Soil Microbiology), R. W. Kerr (Insecticides), K. Norrish (Pedology), Hilary M. Purchase (Soil Microbiology), J. P. Quirk (Physics), H. R. Samson (Physics), R. Thomas (Biochemistry)

British West Indies: W. D. Burrowes (Statistics)

Canada: E. Helen Salkeld (Insecticides)

East Africa: Kenya: K. Lerche (Statistics)

Egypt: K. Abaza (Chemistry), El-Seifi Attia (Field Experiments), W. D. Hanna (Entomology), M. Hosni (Entomology)

Denmark: J. T. Jacobsen (Field Experiments), A. Pederson (Field Experiments)

France: Y. Gendron (Plant Pathology), M. Ollagnier (Statistics)

Holland: W. C. Nijveldt (Entomology), Fré Van der Tuin (Nematology), W. S. Volkers (Entomology)

India: K. Rao (Chemistry), B. P. Singh (Entomology), G. S. Verma (Plant Pathology)

Malaya: S. C. Chua (Statistics), I. Watson (Statistics)

South Africa: A. C. Venn (Chemistry)

South America: Colombia—C. Giraldo Holquin (Field Experiments)

Mexico—Ana Maria Flores (Statistics)

Spain: J. Gallego (Nematology)

Sweden: A. Aslander (Chemistry)

Switzerland: H. U. Morgenthaler (Bee Research)

Tasmania: J. H. Wilson (Botany)

U.S.A.: N. Turner (Insecticides)

West Africa: Nigeria—M. P. Mulholland (Statistics)

British Isles: C. M. Bailey (Plant Pathology), J. Beswick (Insecticides), Daphne D. Bishop (Nematology), J. E. H. Brace (Plant Pathology), R. C. Carolin (Botany), E. M. Clegg (Physics), D. L. Curtis (Botany), Muriel E. Davis (Statistics), J. K. R. Gasser (Chemistry), N. E. G. Gilbert (Statistics), P. Grahame (Entomology), T. E. R. Greenaway (Plant Pathology), M. Grieves (Entomology), N. G. Hague (Bee Research), J. J. Hesling (Nematology), M. V. Jackson (Chemistry), N. T. Laurence (Entomology), J. Mahon (Nematology), J. S. G. McCulloch (Physics), A. F. Murant (Plant Pathology), D. W. Murphy (Entomology), D. O. Norris (Plant Pathology), A. E. Palmer (Various Departments), E. R. C. Reynolds (Plant Pathology), J. E. Satchell (Entomology), R. W. Shepherd (Statistics), J. K. W. Slater (Statistics), W. Stiles (Physics), W. B. Taylor (Statistics), Miss S. Vernon-Smith (Plant Pathology), J. Walgrave (Plant Pathology), J. H. Warcup (Soil Microbiology), D. Willrich (Entomology), June Willis (Biochemistry), R. D. Winslow (Nematology), J. K. R. Wood (Statistics).

Soil Survey of England and Wales

Head of Survey	A. Muir, B.Sc., Ph.D.
Soil Surveyors	B. W. Avery, B.Sc.
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	A. Cromptom, B.Sc.
	E. Crompton, M.Sc.
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	D. C. Findlay
	J. F. Harrop, B.Sc.
	C. A. H. Hodge, B.Sc.
	D. W. King, B.Sc.
	D. Mackney, B.Sc.
	D. A. Osmond, M.Sc., Ph.D., A.R.I.C.
	J. A. Pollock, B.Agr.Sc. (N.Z.), M.F. (Minnesota)
	R. S. Seale, B.A.
	C. J. Tapp, B.Sc.
Chemist	H. H. Le Riche, B.Sc.
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Woburn Experimental Station

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Chemist	T. W. Barnes, M.Sc., F.R.I.C.
Assistant for Work ..	G. Pearce

Farm Staff

Farm Manager	J. F. Moffatt, B.Sc.(Agric.), N.D.A., A.I.B.A.E.
Assistant	G. F. Cole
Foreman	A. W. Neill
Farm Workers	C. Hathaway, Clara E. Horn, K. Wilson, W. Wilson
Part-time Workers ..	W. A. McCallum, G. Tyler

Imperial College of Science and Technology

(Research Institute of Plant Physiology)

Director	F. G. Gregory, D.Sc., F.R.S.
Head of Department ..	F. J. Richards, M.Sc.
Scientific Staff	C. L. Mer, B.Sc., Ph.D., A.R.C.S., D.I.C.
	W. W. Schwabe, B.Sc., Ph.D., A.R.C.S.
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	Dorothy Ridgway, B.Sc., A.R.C.S.
Assistant Staff	W. S. Biggs, Maureen Foster, Mary Lawrence

The Commonwealth Bureau of Soil Science

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Consultant Director ..	Sir W. G. Ogg, M.A., Ph.D., LL.D.
Assistant Director ..	W. D. Brind, B.Sc.
Assistants	Mrs. M. K. Milne, B.Sc. Miss K. H. Carver, B.Sc. Miss N. J. Watts, M.A. I. Szladits, Ph.D.
Indexer	Mrs. S. Adams
Clerks	Cynthia M. Horn, Audrey E. Cleeton, Margaret J. Chapman, Doreen Elsworth

The Bureau is one of ten Commonwealth Agricultural Bureaux, and was established at Rothamsted in 1929. Administratively and financially the Bureau is distinct from the Station, but the closest collaboration exists in the work of the two. The Director of the Station is Consultant Director of the Soil Bureau.

The function of the Bureau is to assist workers in soil science throughout the Commonwealth by providing technical information, by promoting contact between them, and by rendering any technical assistance possible when they are in this country. A bi-monthly abstract journal *Soils and Fertilizers*, covering the literature of soil science, fertilizers and the culture of field crops throughout the world is published, together with occasional monographs—*Technical Communications*—on subjects of general interest. To facilitate its work, the Bureau seeks to be well informed as to the personnel engaged in soil work in the Commonwealth and the problems on which they are engaged. Each Government has been requested to nominate one of its staff as Official Correspondent to the Bureau, who acts as liaison officer in Bureau matters and assists in the collection and distribution of information. The issue of technical information is usually free to all workers in soil science who ask the assistance of the Bureau.

PREFACE

The Rothamsted Experimental Station was founded in 1843 by the late Sir J. B. Lawes, with whom was associated Sir J. H. Gilbert for a period of nearly 60 years. Lawes died in 1900 and Gilbert in 1901; they were succeeded by Sir A. D. Hall from 1902 to 1912, and by Sir E. J. Russell from 1912 to 1943 when the present Director, Sir William G. Ogg, was appointed.

For many years the work was maintained entirely at the expense of Sir J. B. Lawes, at first by direct payment, and from 1889 onwards out of the income derived from the endowment fund of £100,000 given by him to the Lawes Agricultural Trust. In 1904 the Society for Extending the Rothamsted Experiments was instituted for the purpose of providing funds for expansion. In 1906 Mr. J. F. Mason built the Bacteriological Laboratory; in 1907 the Goldsmiths' Company generously provided a further endowment of £10,000, the income of which—since augmented by the Company—is devoted to the investigation of the soil. In 1911 the Development Commissioners made their first grant to the Station. Since then, Government grants have been made annually, and at the present time over 90 per cent. of the necessary funds is provided from Government sources—mainly by the Ministry of Agriculture and the Agricultural Research Council.

The main block of laboratories was opened in 1919; another block was erected in 1924 for plant pathology by a grant provided by the Ministry of Agriculture out of the Development Fund; and Red Gables, the house adjoining the laboratories on the north side, was converted into an Administration Building to hold the Commonwealth Soil Bureau, Staff Common Room, and Conference Room.

Since 1945 Rivers Lodge, a house belonging to the Station, on the south side of the laboratories, has been used to provide accommodation for the Statistical Department.

In 1946, Rothamsted Lodge, the dower house of the Estate, was purchased and occupied by the Entomology and Bee Research and Advisory Departments.

In 1947, the plant nematology work under Dr. T. Goodey, of the Institute of Parasitology, was transferred to Rothamsted and a new laboratory was erected to house this department.

Large glasshouses, including special insect-proof houses for virus studies, were added in 1926, 1928 and 1931 by aid of generous grants from the Rockefeller Foundation, the Empire Marketing Board and the Ministry of Agriculture. A new large range of houses, some of which are insect-proof, was erected in 1935 for plant-pathology investigations.

A large new South Wing was completed in 1940, and the old chemical laboratories were reconstructed. These extensions and reconstructions have provided excellent accommodation for the Chemistry, Biochemistry, Physics and Microbiology Departments; in addition a fine range of pot-culture houses was built. A new laboratory has also been built and equipped for workers from the Imperial College of Science and Technology.

The Rothamsted Home Farm of 250 acres came under the management of Sir John Lawes in 1834, the experimental fields being worked from the farm buildings at the Manor House. In 1913 the first range of farm buildings and cottages was erected on the site of the present buildings. These were considerably enlarged in 1930-32 and equipped for electric light and power. Further additions were made in 1939-40, and the electricity supply has now been extended to these newer buildings.

A further range of six farm cottages was erected in Ninnings Field in 1948, and a concrete road constructed from the back of the laboratories to the farm.

The non-experimental part of the farm was reorganized in 1928 to meet the prevailing economic conditions, much of the land being laid down to permanent grass, and cattle and sheep were introduced. In 1939 this policy was reversed, ley farming was introduced, and the arable acreage was increased to meet wartime conditions.

The extension of the experiments to various outside centres in Great Britain, begun in 1921, has proved so advantageous that it has been developed. Not only is useful information spread among farmers, but the Station gains considerably by this closer association with the Universities and Advisory Services. As part of this extension, the Station took over in 1926 the Woburn Experimental Farm. We were thus able to make experiments simultaneously on the light land at Woburn and the heavy land at Rothamsted.

In May 1934, the negotiations for the purchase of the farm and some adjoining parts of the Rothamsted Estate were completed. The Rothamsted Trustees now own the site of the laboratories, the experimental and ordinary farm fields, Knott Wood, the Manor House and grounds, the farm manager's house, and eight cottages. The total area is 527 acres. The purchase price was £35,000, all of which was raised by public subscription. Generous contributions were received from Sir Robert McDougall and others, and a highly encouraging feature of the appeal was the number of subscriptions received from farmers, village school teachers, and from oversea sources.

The activities of Rothamsted, however, are not confined to the British Isles, but are gradually spreading out to the Commonwealth and other countries. The Station regularly participates in work for the solution of agricultural problems of great importance to the Commonwealth.

The Station offers research facilities for post-graduate students, but unfortunately the number of additional workers that can be accommodated is at present strictly limited by lack of laboratory space.

The Commonwealth Bureau of Soil Science, one of the ten Commonwealth Agricultural Bureaux set up to act as clearing centres of information on agricultural science, has been located at Rothamsted since its establishment in 1929.

The Library

The Library may be said to have come into being in 1913, when the Sir Henry Gilbert Collection, presented by Lady Gilbert, was added to the small body of reference works used in the Laboratory at that time—most of them the gift of Sir John Lawes himself.

Its expansion, aided by gifts and grants from a number of individuals and Societies, was rapid, until it now contains:

	(Approximately)
Periodicals .. .. (Current, 1,100)	2,500
Books, 1841-	10,000
Books, 1471-1840 .. .. .. (including 14 incunabula)	3,500
Bound volumes of pamphlets ..	350
MSS.	55
Maps	300
Prints	100

—in all about 17,000 items, comprising some 38,000 volumes.

The yearly accessions of books and periodicals, bought and exchanged, amount to approximately 1,100 volumes.

The chief periodicals on agriculture and related subjects published throughout the world are received, either by subscription or in exchange, and constitute the most used section of the Library.

The stock of books also covers a wide range of subjects—not only agriculture but also, e.g., chemistry, physics, biology, botany, geology, zoology, meteorology and statistics. The books are arranged according to the Universal Decimal Classification system. The collection of early printed books (1471-1840), which is kept separate from the rest, includes 14 incunabula, amongst which is a copy of the first dated edition of Pier de' Crescenzi's *Ruralium commodorum libri duodecim*—the earliest printed book on agriculture—produced at Augsburg by Johann Schüssler in 1471 (Hain 5828). The collection of MSS. includes a copy of the *Treatise of Husbandry* by Walter of Henley (fl. 1250), written in England on vellum about the middle of the 14th century.

The prints, which are mainly of the 18th and early 19th centuries, include portraits of eminent agriculturists, bucolic scenes, and representations of livestock. A most valuable addition to this collection was made in 1948 when Lord Northbrook presented his Father's collection of prints to the Station.

The Library is designed to meet the requirements of the staff of Rothamsted; but its use is extended to any research worker who can show his need of it.

The General Catalogue of the Library is kept on cards. There is also a published catalogue of the collection of early printed books (Rothamsted, 1926; second edition, 1940) of which a third edition, completely revised and expanded, is being prepared.

INTRODUCTION

By The Director

Staff

Dr. R. K. Schofield was granted leave of absence at the end of October to take up a six months' appointment as Visiting Professor of Soil Physics in the Department of Agronomy, Cornell University, and Dr. H. L. Penman was awarded a Nuffield Foundation Fellowship to enable him to spend six months at the Waite Institute, Adelaide, Australia, to study irrigation research and water loss from vegetation. Dr. E. M. Crowther made an eleven week tour of the eastern half of the United States on an E.C.A. grant to study soil fertility and fertilizer investigations. Dr. F. Yates visited Jamaica to lead a seminar on sampling methods organized by the Institute of Social and Economic Research of the University College of the West Indies and spent a brief period at the Imperial College of Tropical Agriculture, Trinidad. He also gave a series of lectures in Sweden on modern statistical technique, and during a visit to Brazil lectured at the University of Sao Paulo and in Rio de Janeiro. In December he attended the fifth meeting of the United Nations Sub-Commission on Statistical Sampling held in Calcutta and visited various Institutes and Research Stations. At the invitation of the Consejo Superior de Investigaciones Cientificas, the Director spent three weeks in Spain lecturing at various centres and visiting research institutes. Mr. J. R. Moffatt spent about three months on the Continent studying farming and field experimental methods, and Dr. T. Goodey visited several European centres engaged on nematological work. Dr. P. H. Gregory visited Kenya to advise on the "bud disease" of pyrethrum, and Dr. R. Hull spent two months in the United States studying sugar beet diseases work there. Dr. C. Bloomfield took part in an E.C.A. Mission to West Africa to study the formation and development of laterite.

Rothamsted was represented at the 2nd International Congress of Crystallography, Stockholm, the 9th International Congress of Entomology, Amsterdam, the Conference on Potato Virus diseases, Wageningen, and the 14th International Beekeeping Congress. At the invitation of the Organizing Committee, Mr. F. C. Bawden attended the International Poliomyelitis Conference at Copenhagen. Dr. E. M. Crowther gave the Presidential Address to Section M (Agriculture) of the British Association in Edinburgh in August. Dr. C. B. Williams has been elected an honorary member of the Netherlands Entomological Society, and the degree of LL.D. was conferred on the Director by the University of Aberdeen.

Mr. Neely Turner of the Connecticut Agricultural Experiment Station spent six months in the Insecticides Department in exchange for Dr. A. H. McIntosh and his visit proved of great benefit to the department.

Visitors

The number of research workers and farmers visiting the Station has shown an increase, and, owing to the Festival of Britain, the proportion of overseas visitors was higher than usual. They included Mr. Charles Brannan, the United States Secretary for

Agriculture, the Ministers of Agriculture for Sweden and Queensland, the United Nations Committee on Coordination of Agriculture and Research, the principal chiefs and advisers of the Paramount Chieftainess of Basutoland, and a party of French journalists. Amongst the conferences and courses held at the Station during 1951 were a conference for research workers on the use of insecticides and fungicides, a course on insecticides for overseas workers sponsored by the British Council, an international nematology course and symposia sponsored by the Food and Agriculture Organization, an international conference of bee research workers, and a conference of the Clay Minerals Group of the Mineralogical Society.

Buildings

The conversion of the old sample house near the main laboratory buildings into a library annexe and institutional store for apparatus and equipment has been completed. Progress has also been made with the flats and hostel accommodation at the Manor House, but unfortunately sanction has not yet been obtained for the new buildings for Statistics and Plant Pathology, and lack of accommodation is a serious problem.

The Work of the Station

In the Pedology Department, much attention has been given to mineralogical studies of soils and soil clays. Amongst the soils examined were samples from the Kongwa area of the Tanganyika groundnut scheme, the Equatorial Provinces of the Sudan, and an area of the Gold Coast near Accra. The general mineralogical character of soils of comparable origin in Tanganyika and the Sudan was found to be very similar. It was also found that the "cracking clays" of the Sudan appear to be characterized by a mineral of the montmorillonite type which swells and shrinks strongly on wetting and drying. Further work has been done on clay minerals, including their quantitative determination and improvements have been made on the X-ray equipment for their study. The interaction of clay and soil organic matter is important and in this connection the adsorption complexes between one of the clay minerals and organic molecules, including large protein molecules, have been studied. Progress has been made with the investigations of ill-drained soils and it would appear that the grey material in such soils may be the end-product of the reduction process and that the rusty brown material is usually a form of hydrous ferric oxide.

Shortage of sulphur has led to increased interest in phosphatic fertilizers which can be made without the use of sulphuric acid and the Chemistry Department has devoted much attention to the subject. Field experiments have been carried out with dicalcium phosphates, silicophosphate and ground Morocco mineral phosphate in comparison with superphosphate. It is too soon to draw conclusions but in 1951 with potatoes, dicalcium phosphate gave somewhat better yields than superphosphate on the average of thirteen experiments, whilst silicophosphate was less effective, and mineral phosphate still less so. For swedes, all three gave yields approaching those with superphosphate. The experiments also

showed that quite small dressings of superphosphate often suffice to give good crops and one of the obvious adjustments to present shortages and high prices of phosphate fertilizers is to use less on land with appreciable reserves from past treatment. Experiments are also in progress with nitrophosphates made by two different processes and it has been found that one is superior to the other. There are indications from this that the size and stability of the granules may be important factors in the rate of action of the less soluble phosphate fertilizers.

Experimental work on fertilizer placement has been continued and extended. The advantage in the case of peas and beans of placing the fertilizer beside the seed has been shown over four seasons and where special placement drills are not available, farmers are advised to incorporate the fertilizer for these crops in the soil by ploughing or cultivation. Experiments on leys indicate that broadcasting the fertilizer generally gives better yields than applying it in bands below the surface. Preliminary results on potatoes planted by machine show that fertilizer placed in contact with the seed, or in bands beside it, gave higher yields than fertilizer broadcast on the flat or placed in front of the seed-shoe of the planting machine. It should be noted, however, that direct contact with the seed may be dangerous in dry spells.

Further work has been done on materials that might be used to supplement the inadequate supplies of slow-acting nitrogenous fertilizers and promising results have been obtained from formalized casein and from a product prepared from urea and formaldehyde. The work on the manuring problems of forest nurseries has been continued and the effects of formalin treatment of the soil further investigated. It has been found that Sitka spruce seedlings on acid soils are particularly sensitive to nutrient deficiencies and symptoms of lack of potassium and magnesium have been identified in the foliage. Progress has been made in the investigations on soil organic matter especially on the proteins and amino acids which it contains. Further work on the Classical plots at Rothamsted confirms earlier indications that phosphorus fertilizers may have residual effects extending over very long periods though only a small amount may become available in any one year.

In the Physics Department a good deal of attention has been given to soil structure. The physical effects of grass roots have been studied and evidence obtained that after the stems have been cut off and the roots are dead, they continue to conduct water and thus improve drainage. It is possible, therefore, that one of the physical effects of grass may be the prevention of the deflocculation of the surface soil layers in very wet conditions. The influence on soil structure of the concentration of salts in the soil solution has also been studied and a simpler method devised for determining the critical salt concentration below which soils are deflocculated. In irrigation schemes there is sometimes difficulty in maintaining good structure in the soil, but if the chemical composition of the irrigation water is known, the stability of the soil structure can be predicted and corrective measures applied when necessary.

An irrigation experiment designed to give detailed information on the times and levels of watering in conjunction with nitrogenous

manuring at two levels has been laid down at Woburn, the crops being grass, spring barley, sugar beet and potatoes. The equipment was not ready in time to allow the full watering programme to be carried out, but, during this trial run, substantial benefits were obtained from the application of a few inches of water. Work has been continued on soil cultivation, evaporation and various other subjects.

In soil microbiology one of the main problems facing the research worker is that of discovering what particular microorganisms are responsible for certain chemical changes which are known to occur in soil. A study from this point of view is being made of reduction processes in soil. The reduction of ferric iron and of sulphates has an important bearing on soil formation processes and on the availability of plant nutrients whilst the reduction of nitrates affects nitrogen losses from soil. Such reduction processes used to be regarded as evidence of the existence of anaerobic conditions, at least locally, in the soil. Investigations carried out during the year on sulphate reduction however, show that it can take place in the presence of oxygen, and an aerobic sulphate reducing bacillus has been isolated. This is in line with previous work in the department on denitrification. In the case of iron, bacteria which can reduce ferric oxide in the presence of sugar have been isolated and their further study should throw light on the movement of iron in the soil.

Another line of investigation deals with the extent to which the addition to soil of a novel chemical compound will encourage the development of a specific microflora that can attack it. This has a very important bearing on the persistence in soil of the insecticides and weed-killers that are now added at times either intentionally or by accident. For this reason, the decomposition in soil of organic compounds containing chlorine and bromine is being studied from a bacteriological point of view. The building up of a specific flora of this sort is a special case of an induced change in the micropopulation.

A study of the more general effects of partial sterilization on the soil population, referred to in the 1950 report, has been continued, as has also an investigation of the effects of antibiotic actinomycete secretions on root disease fungi. The work on nodule bacteria and leguminous plants has made progress and further interesting results have come from the study of root secretions in affecting both the numbers of nodule bacteria in the root surroundings and the number of nodules produced. The progress of other lines of study will be found described in the report of the department.

In the Botany Department, work has been continued on micronutrients or trace elements and on the physiology of the uptake of plant foods by roots. The latter investigation has now been extended from excised roots to intact root systems to see if ion absorption is accompanied by increase in rate of respiration. Further progress has also been made with the study of the uptake of nutrients from solutions sprayed on the leaves. Sugar beet plants sprayed several times in late August and September with a solution of ammonium nitrate showed a marked increase in the dry weight and protein of the leaves and 80 per cent of the nitrogen applied was recovered in the plants. From further studies of the influence of moisture

on germination, it has been concluded that conditions in the soil are rarely so dry as to inhibit germination; failures in establishing crops during drought are due to lack of water in the post-germination stage and increased death rate of seedlings through fungus attack.

In studies on the biology of wild oats it has been found that farmyard manure hastens the germination but reduces the viability of their seeds and that the seeds of one species (*A. fatua*) germinate more readily if sown in the surface soil whilst those of another species (*A. ludoviciana*) germinate better at a depth of several inches. Only 7 seeds of *A. ludoviciana* out of 2,000 fed to a calf have so far germinated in the excreta. A survey carried out in co-operation with the National Agricultural Advisory Service showed that the species *A. fatua* occurs throughout the eastern, midland and southern parts of England but in Wales was found only in Monmouthshire. *A. ludoviciana* has a much more restricted range and was recorded only from an area roughly within a radius of 80 miles of Oxford.

In the Plant Pathology Department much of the work, as heretofore, has been on virus diseases. The effects of ultra violet radiation on viruses and on plants were studied. This treatment reduces the infective power of viruses and in some cases, the infectivity is less when the inoculated leaves are kept in darkness. The damaging effects of ultra violet rays on the leaves themselves is counteracted by keeping them in daylight after irradiation. Virus infection is inhibited by extracts from certain plants and it has been shown that this effect is greater when the extract is from a plant of a different species; two substances which cause the inhibition have been separated from a plant extract. The influence of temperature on susceptibility to virus infection has also been studied and it has been found that exposing plants to a temperature of 36°C. before inoculation greatly increases susceptibility to several viruses. On the other hand exposure to heat after inoculation reduces infection and in the case of some viruses wholly prevents it. Work on sugar beet yellows has been continued and it has been found that the strains of viruses causing this disease reach higher concentrations in the infected plants than was the case a few years ago. It has also been shown that yellowing diseases of beet can be caused by several viruses, some of which have no connection with sugar beet yellows, and one of them is seed transmitted. In 1951 the field experiments on the spread and control of virus diseases in potato, sugar beet and cruciferous crops was hampered by the unusually small population of aphids and the consequent small spread of viruses; sugar beet stecklings were healthier than for many years and lifted roots over-wintered well in clamps.

Good progress was also made with the study of fungus diseases. Laboratory and field work on the dispersal of spores showed that the spore trap customarily used gave inaccurate results and a more efficient trap has been designed which gives continuous records of spore concentrations. These have shown, for instance, that the spores of potato blight spread mainly in the morning. Another observation on potato blight was that tubers infected in the field in 1950 produced plants with blighted shoots in 1951. Work on cereal mildews showed that *Erysiphe graminis* infections develop

soon after dressings of readily available nitrogen have been applied to a crop. The investigations on take-all and eyespot have been continued and it has been shown that after two years under non-susceptible crops the former disappeared and the latter was much reduced; spraying with H_2SO_4 was again effective in reducing eyespot. The mummy disease of mushrooms was also studied and it has been shown that it is not caused by a virus.

The Biochemistry Department is investigating the nucleoproteins from normal and virus infected leaves, the technological production of leaf protein, the oxidation of manganese by plant extracts and the part played by fungal mycelia in building up soil organic matter. These rather diverse lines of work although started independently are now becoming more integrated. Thus the study of the range of nucleoproteins formed in the leaf during virus infection connects well with the work on the normal nucleoproteins of the leaf and on the enzyme actions they undergo and bring about. Again, the work on enzyme mechanisms that play a part in the manganese metabolism of the plant suggest other possibilities of interaction. It is now clearly established that there are mechanisms in the plant that can make hydrogen peroxide and that the latter can oxidize manganese with the help of the enzyme peroxidase but it has not yet been shown that this is the normal process. The investigations on the rôle of the resistant parts of fungal mycelia in the formation of soil organic matter have benefitted greatly from the experience already gained on the decomposition of leaves by enzymes and the latter was in fact undertaken in connection with the liberation of viruses from leaves. Chitin and some other polysaccharides have been isolated from several species of fungi and a survey is being made of the enzymes of fungal, bacterial or invertebrate origin that can attack them. In the course of the work on the production of leaf protein, improvements have been made in the extraction process and material from various crops has been prepared for chicken feeding experiments.

In the Nematology Department work has been continued on a wide range of eelworms and new species discovered include one associated with a root disease of oil palm seedlings and one destroying flower heads in Caucasian scabious. Studies are being made of the various strains or races of stem eelworms which attack oats, onions, certain flower bulbs and many other crops and weeds. From the farmer's point of view it is important to know what crops and weeds are attacked by the various races but the problem is complicated by the fact that many plants may be attacked by more than one race. For example the broad bean is attacked by both the oat and a " giant " race but not by the red clover race. Attempts are being made to find immune varieties of crops and a few spring varieties of oats have shown resistance to the oat race.

Further work has been done on the potato root eelworm. The search for substances to control this pest has been continued and several show a certain amount of promise. A three year field trial has shown that the use of the substance known as D.D. mixture is economically possible on certain soil types but not on black fen soils, and a new experiment has been started to ascertain the best stage in a crop rotation at which to apply it. The changes in

eelworm numbers during a rotation are also being studied. It has been known for some time that a substance diffuses out of potato roots which stimulates eelworm larvae to hatch and this substance can now be standardized by a biological method. It is produced most abundantly in the early stages of the plant's growth. The black nightshade and certain other plants also produce a diffusate and this suggests the possibility of controlling potato root eelworm by means of a trap crop.

The work of the Entomology Department has continued on the lines of previous years, namely, studies of insect population, causes of outbreaks of insect attacks and investigations of problems relating to particular pests. Studies of the numbers of aphids at different levels in the air have shown that by far the greater proportion of those flying during the day are at altitudes above 100 feet and thus subject to considerable dispersal by air currents. The number in the air at any particular time, however, depends more on such factors as population and environment than on weather conditions. Work is also in progress on the natural enemies of aphids which include ladybird beetles, hover-fly larvae, lacewings and mites.

Studies of gall midges have been continued and include investigations into the range of host plants of the swede midge. Further work has been carried out on wireworms and on the effects of insecticides in controlling them. Progress has also been made in the study of earthworms and of forest soil insects.

In the Bee Department, much attention has been given to bee behaviour and to the foraging behaviour of wasps and bumblebees. The influence of scent, both that produced by flowers and also by the bees themselves has been investigated. It has been confirmed that as floral perfumes are generally rather weak and a worker honeybee's sense of smell being similar to that of man, she has to approach a flower very closely before appreciating its scent. Once she has learnt to associate the scent of a particular species of flower with food, she hesitates to enter any flower of this kind unless she can smell its perfume. This probably explains the observed temporary repellent effect on bees of many insecticidal and herbicidal sprays. It has also been shown that on nearing a source of food bees are helped to find it by the scent produced by bees already there.

The organization of bees in their colonies has also been studied and it would appear that the age of a honeybee is not the factor which determines the work she undertakes. The egg-laying activities of the queen have been investigated and also the behaviour of bees before and after swarming. The work on the composition and secretion of nectars of the more important species of flowers visited by bees, has been continued and the physiology of pollen digestion is being investigated. The extent of food transmission between the bees of a colony has been studied by means of a radioactive tracer and work on bee breeding has been continued.

The effectiveness of an insecticide varies with the species of insect on which it is applied and the reasons for this variation are being investigated by the Insecticides Department as part of their research programme. One group of insecticides, the organophosphorus compounds, is believed to act by inhibiting the esterase

enzymes of the insect. It has been shown that esterases from different species of insects are different and this may be one reason for the differences in the effects of the organo-phosphorus compounds on different species of insects. In view of the very considerable human hazards attached to the use of many of the modern synthetic insecticides a considerable amount of time has also been devoted to the study of pyrethrum and the synthetic compounds akin to the pyrethrins which are, for all practical purposes, non-poisonous. Some progress has been made in determining the structural features of the molecule which are essential for insecticidal activity and a physical method for the separation of Pyrethrin I from Pyrethrin II has been worked out.

Some of the modern insecticides such as D.D.T. when sprayed on to a surface can form a protective coating that will kill insects and may last for a considerable time. A persistent protective insecticidal film is, of course, a useful means of insect control. When D.D.T. is applied to a plant surface the degree of effectiveness of the protective film and the length of time which it lasts varies a good deal and some work has been done on the reasons for the variation. It has been shown, for instance, that D.D.T. vapour can be absorbed by the surface wax of the plant and that the insecticidal activity of a film of D.D.T. is affected by the nature of the leaf surface and varies with the species of leaf on which it is applied. It appears that a film of D.D.T. on a leaf surface has a greater insecticidal activity than a similar film on a glass surface. Field experiments on the control of wireworms have shown that Aldrin and Chlordane give promising results and experiments on the control of black aphis on field beans have indicated that effective control of the aphis and a greatly increased crop yield can be obtained by a single application to the beans at a very early stage of infestation of any one of several different insecticides.

The Statistics Department has continued to design and analyse field and laboratory experiments for Rothamsted and various other research stations, and close contact with the National Agricultural Advisory Service has been maintained. The computations arising from this side of the work have involved the analysis of nearly 60,000 plot yields during the year. Work has been continued on the Rothamsted experiments and on various surveys. The Survey of Fertilizer Practice covered 11 counties during the year, and the field work of a Survey of Restored Opencast Coal Sites was completed. Other surveys analysed during the year concerned brassica crops grown for stock feeding in Wales, rabbit damage to winter wheat and ragwort infestation in Anglesey and Pembroke. The department is assisting the National Institute of Agricultural Engineering in an operational survey of farm tractors and final figures for the Survey of Maincrop Potatoes have confirmed results obtained in previous years. Critical summaries of published data on various branches of agricultural practice have been prepared, and the department has also studied the relative merits of a variety of laboratory and field techniques used by the National Agricultural Advisory Service and other organizations.

Long period experiments on modern problems of manuring, cultivations, and rotations were continued in 1951 on both

Rothamsted and Woburn farms. The ley-arable rotations are both now in full cycle and, as in the previous season, the second-and third-year lucerne plots in this experiment produced more dry matter per acre than any of the old or seeded grass mixtures with which they were compared. The three-course rotation begun in 1933 to test raw straw and straw compost was terminated and the original treatments have been recast to study certain points arising out of the action of straw in this experiment. The Woburn irrigation plant has already been mentioned and the rotation in the market garden experiment at Woburn was recast in 1951 to allow of a somewhat longer period of growth for the crops grown, the organic manuring being unchanged.

The annual experiments have been continued. Top dressings of " Nitro-chalk " applied to cereals late in the season when the crops were in ear once more raised the nitrogen content of grain and straw but not quite to the same extent as in the previous year. Machine-planted potatoes again out-yielded those planted by hand and further experiments to study this effect and the location of fertilizer in relation to the seed are being designed. In all 2,445 experimental plots were handled in 1951.

At Woburn the work on certain exotic crops has been continued and in spite of the unfavourable season some Continental strains of soya beans ripened but the yield was low. Early varieties of hybrid maize were tested and this crop may have some future in certain districts. Heavy yields of green fodder were again obtained from yellow lupins and serradella and birdsfoot trefoil also gave satisfactory results. Progress has been made with the studies of weeds and further work done on clover sickness.

The farm manager and his staff have as usual given most willing cooperation and much valuable assistance to the scientific departments in all their experiments both at Rothamsted and Woburn.

DEPARTMENT OF PHYSICS

By R. K. Schofield

Dr. W. C. A. Hutchinson resigned in September and joined the research staff of Imperial Chemical Industries at Billingham. Mr. D. Pearce was awarded a National Certificate in Chemistry.

Mr. H. R. Samson of the Division of Industrial Chemistry (Ceramics Section) of the Australian Commonwealth Scientific and Industrial Research Organization and Mr. J. S. G. McCulloch of Edinburgh University joined the department for a two years' period.

Dr. Schofield has continued to serve on the Joint Committee on Soils appointed jointly by the Department of Scientific and Industrial Research and the Ministry of Supply. Dr. Penman has served on the Council of the Royal Meteorological Society and the Board of the Institute of Physics.

Dr. Schofield was granted leave of absence at the end of October to take up a six months' appointment as Visiting Professor of Soil Physics in the Department of Agronomy of Cornell University. For the same period, Dr. Penman was given a Nuffield Foundation Fellowship to enable him to spend six months in Australia, based on the Waite Institute, Adelaide, to study water loss from plants and irrigation research. Mr. G. H. Cashen was left in charge of the department during their absence.

Soil Cultivation

Deep ploughing

The weather has had a decisive influence on the effect of deep ploughing on the yield of potatoes. During the very wet winter the plots were usually waterlogged at plough bottom after rain, that is at 6-8 inches and at 12-14 inches on the shallow and deep ploughed plots respectively. As judged by tensiometer tests, movement of water was impeded on the dunged plots. Thus just before spring cultivation the plots in order of dryness were deep undunged, shallow undunged, deep dunged, shallow dunged. The disked plots would normally have the advantage of a better tilth, but this was completely outweighed by the long period without rain immediately after planting. The dry weather also accentuated the effect of fertilizer placement, the plants being unable to reach the ploughed-in fertilizer. Eye scores taken on July 3 on the general appearance of the plots gave highly significant differences in favour of fertilizer applied in the bouts, and the shallow ploughed plots as a whole were significantly better than the deep ploughed plots. The deep ploughed plots never attained the same growth as the shallow ploughed plots as the more backward plants were attacked by blight in August. This is borne out by the final yields of a poor crop (mean yield 4·8 tons per acre): the deep ploughed plots were significantly lower than the shallow ploughed plots whatever the method of applying the fertilizer; and the plots with fertilizer ploughed in were significantly lower than those with fertilizer applied in the bouts. In particular, the deep ploughed plots with 1 cwt. K_2O applied in the bouts yielded 1·7 tons per acre less than

the corresponding shallow ploughed plots, in contrast to slight increases in the previous six years. There is as yet, therefore, no significant benefit from deep ploughing for potatoes.

This year the deep ploughed plots have yielded 34 cwt. per acre of sugar compared with 29½ cwt. per acre for the shallow ploughed plots so that in six out of the eight years the experiment has been running there has been a small increase in the yield of sugar, due to deep ploughing. The best effect from 0·6 cwt. P_2O_5 per acre as superphosphate was obtained by harrowing it into the seed-bed of the deep ploughed plots. This is in contrast to previous years and is probably again due to the very long dry spell immediately after disking preventing the young plants from reaching the fertilizer.

Of the crops in the rotation, considering the yields over the years there is no net gain to be derived from deep ploughing for wheat. There is no net residual effect on the following spring barley and undersown ryegrass-clover ley from deep ploughing for sugar beet. For the first time there has been a significant increase in the yield of spring oats after potatoes on the deep ploughed plots. However, taken in conjunction with the yields over the six years, there has been a small net loss.

Agricultural Meteorology

Irrigation

The results of the sugar beet experiments in 1948, 1949 and 1950 have been collated to see how far they can be unified in spite of differences of season, soil, and virus infestation. The result has been encouraging, for by plotting sugar yield as a fraction of an estimated maximum for the site and season against calculated soil moisture deficit coherent distributions of points have been obtained. From these diagrams it appears that mid-season deficit is probably more important than end of season deficit, i.e. early watering is probably better than late watering, and that yields are not appreciably reduced provided the mid-season deficit does not exceed about 2 inches, or if the end of season deficit does not exceed about 4 inches. The main value of this analysis lies in the clues it has provided for design of the more detailed experiments started this year at Woburn.

Four crops occupy the three acres being used at Woburn. Grass, to be cut frequently as though for grass drying, has been laid down for three years: the remainder of the area carries a three course rotation of a spring cereal (barley in 1951), sugar beet, and early potatoes with a brassica crop after (cabbages in 1951). During early 1951 an overhead spray system was installed, but contractors' delays were such that it was mid-June before even a low pressure water supply was available, and the end of July before pumping at the planned rate was possible. The effect has been that the full variety and intensity of desired watering treatments was not achieved. Results will not be given or discussed in detail until a few years' data are available, but as an indication of trends, yields and relevant waterings for the unirrigated plots (O) and the most watered plots (C) are given in the following table. All plots were given a basic fertilizer treatment including nitrogen (N_1), and half plots had an extra nitrogen dressing (N_2). The end of the

period is arbitrary for the sugar beet, but for the other crops it is approximate harvesting date (third cut for grass).

May, June and July were dry and once irrigation could be started all crops except barley showed obvious benefit from extra water. These visual impressions were confirmed by the final yields:—

Woburn Irrigation 1951

Crop	Period	Rain	Irrigation (inches)	Plot		Yield
Grass ..	May 1–Sept. 4	8·8	—	ON_1	6·7	tons per acre
				ON_2	9·5	(green)
		8·8	3·6	CN_1	12·1	
				CN_2	13·5	
Sugar Beet	May 1–Sept. 17	9·9	—	ON_1	43·5	cwt. per acre
				ON_2	56·8	(sugar)
		9·9	3·4	CN_1	46·0	
				CN_2	62·5	
Barley ..	May 1–Sept. 3	8·8	—	ON_1	21·7	cwt. per acre
				ON_2	30·1	
		8·8	3·2	CN_1	29·0	
				CN_2	33·0	
Potatoes ..	May 1–July 30	3·9	—	ON_1	3·85	tons per acre
				ON_2	3·75	
		3·9	2·2	CN_1	7·65	
				CN_2	8·55	

Heat balance of the soil

Dr. Hutchinson continued his recording of soil temperatures and had begun to analyse some of the records when, unfortunately for the department, he took up a new post elsewhere. During the year, with the assistance of Mr. Long, he set up a continuously recording system of wet and dry bulb thermometers (thermistors) at six heights up to 6 feet; and, on the tower, set up resistance thermometers at 20 feet (dry), 40 feet (wet and dry) and 80 feet (dry). Mr. Long built another double recording anemometer, so that continuous wind speed readings are now being taken at 3, 6, 40 and 80 feet above ground.

On selected days, Dr. Hutchinson has used Robinson's technique (from Kew Observatory) for measuring radiant energy fluxes to and from the ground: analysis of these results will be very much delayed.

Mr. McCulloch has started a study of the interrelations of flow of heat and flow of water (as liquid or vapour) in the soil.

Evaporation and transpiration

The chief new extension of previous work has been in the working out of the water balance of the Thames catchment area, month by month from 1930 to 1949. Making reasonable assumptions about unmeasurable unknown quantities good agreement has been obtained between estimated changes in storage and observed changes in well level.

Miscellany

Application of the standard theory of atmospheric turbulence has shown that Dr. Johnson's records of changes of aphid density with altitude lead to a reasonable value for the clearance rate under calm evening conditions.

Soil Physics

Soil structure and grass roots

From his last year's work Mr. W. W. Emerson concluded that the favourable structure induced by a period under grass could not be explained in terms of improved water stable aggregation. Accordingly a study was made of various Rothamsted fields during the winter 1950-51 in relation to their cropping history, in particular comparing Barnfield, continuous mangolds, and Highfield, just ploughed out of permanent grass. Water movement was followed by means of tensiometers placed at intervals from the soil surface into the subsoil. With the extremely wet weather Barnfield soon became waterlogged at plough depth, the tensiometers merely recording their height above the furrow bottom. Highfield, on the other hand, although saturated in the turf where it had been inverted, always showed a tension at the surface of over 30 cm. of water. The difference, too, in the general appearance of the two fields was remarkable. The surface soil of Barnfield was very compacted and extremely sticky, while the surface of Highfield was relatively dry and had preserved its crumb structure intact.

The difference could be accounted for by the ability of grass roots to conduct water under tension ; that is, sucking the water from the surface into the turf. Cross-sections of *Lolium perenne* showed one or two central metaxylem vessels of the order of $3{\cdot}0 \times 10^{-3}$ cm. diameter. Experiments on the rate of water conduction through severed *Lolium* roots corresponded to a hydraulic diameter slightly less than that given by hand sections. Microtome sectioning, carried out by Mr. Carolin (a temporary worker in the Botany Department), confirmed that the metaxylem vessels are continuous except for occasional very slight constrictions. Several other grasses were investigated, and all behaved similarly. In *Dactylis glomeratus* the metaxylem vessels are less than 1×10^{-3} cm. diameter, so that as water conduction depends on the fourth power of the diameter this grass will conduct a negligible quantity of water compared with other grasses.

To obtain the maximum benefit from these roots it would be better not to invert the turf, but to sever the roots immediately under the stolons. Then the root tip, being the newest tissue, would rapidly decay and a natural drainage system would be left for conducting water into the subsoil. Experiments will be made to compare shallow rototilling with ploughing.

The above type of continuous metaxylem cavity is confined to monocotyledons and may explain why Broadbalk continuous wheat has still a good structure compared with Barnfield continuous mangolds.

The possibility of simulating the action of dead grass roots by incorporating straw more or less vertically will also be tried. It has already been shown in the laboratory that the metaxylem cavities in the periphery of the straw are continuous through the nodes into the leaf sheaths.

Unsaturated flow of water in soil

Starting with very loosely packed sieved aggregates Mr. Emerson has found that the distribution of water at a given pressure deficiency

can be treated as arising from a re-packing for which the pore space is similar to that occupied by water in the unsaturated case. Thus Kozeny's equation for the absolute variation of saturated flow with packing should apply to the variation of unsaturated flow with moisture content, where the moisture content per unit volume is substituted for the degree of packing. This was confirmed by the results of Childs and George on sieved sands, and values for the surface area derived are in very good agreement with other methods. Plotting permeability against pressure deficiency showed that the permeability decreased by a factor of 10^4, due to air entry into the intergranular pores—a quantitative explanation of the well known phenomenon of field capacity.

The method used by Childs and George for sands breaks down at very low permeabilities. It has been found possible, however, to compute unsaturated permeabilities from the rate of attainment of equilibrium in the normal method of determining moisture characteristics. This has been used to determine the permeabilities of 1-$\frac{1}{2}$ mm. sand at very low moisture contents up to the limit of liquid flow. The method is quite general and is being applied to 6 inch diameter field samples.

Soil/water relationships

Mr. G. H. Cashen, besides taking over the administration of the department during the absence of Dr. Schofield and Dr. Penman has rounded off and written up his work on the vapour pressure of aqueous solutions, the results of which have been given in previous reports. The work on the thickness of water films on mica and clays, which had been temporarily suspended, has been taken up again.

Physical Chemistry

Ions in soils

In view of the complex chemical behaviour of free aluminium ions in solutions in equilibrium with soils, Mr. A. W. Taylor has turned his attention to a more rigorous checking of the theoretical principles on which this study of the behaviour of ions in soil solutions is based. A series of experiments was carried out to examine in detail the changes in hydrogen ion activity in soil in equilibrium with sodium, potassium, calcium and aluminium salt solutions over wide ranges of concentration.

The results obtained were in close agreement with those predicted from the theoretical study based upon the Gouy theory of the electrical double layer, and indicate that this theoretical treatment may be used with confidence in the interpretation of the study of equilibrium conditions in soil solutions.

The experiment in which the changes in pH of the calcium saturated soil in equilibrium with calcium chloride solutions of various concentrations were measured has confirmed the view that M/100 $CaCl_2$ is the most satisfactory solution to use in the determination of soil pH values.

The standardization of the electrolyte concentration at this level has the great advantages that the result obtained using a normal pH meter is independent of the soil/solution ratio, and that

erratic variations due to suspension effects present when the soil is dispersed in water are absent.

This reagent is now used as the standard reagent for the measurement of soil pH in this laboratory, and it has been found that the results obtained are more reproducible and reliable than water measurements.

In view of the importance of aluminium in soils, particularly in connection with the buffer capacity of clays, the study of the hydrolysis of aluminium chloride solutions has been extended so as to obtain more detailed information about the electric charges present on freshly precipitated aluminium hydroxide. It is already clear that, at the "end point" around pH 7 where the system is practically unbuffered, the precipitate still carries a few positive charges. A suggested structure for the colloidal precipitate places these charges at the end of chains of aluminium ions linked together by pairs of hydroxyl ions. If this interpretation can be substantiated it enables the average length of the chains to be determined. The work on this problem is being continued.

Critical salt concentrations for deflocculation of soils

The deflocculation of soil has been investigated by Mr. J. P. Quirk using a permeability method and single ion systems. At sufficiently high salt concentrations steady flow occurs through a soil pad (1 cm. thick and 5 cm. diameter), but when the electrolyte content of the percolating liquid is reduced beyond a critical level for each ion (deflocculation concentration) decreases in permeability are noted. The ions used were those practically important in soils, viz. Na, K, Mg and Ca.

Measurements have been made of the activity product $[H] \times [Cl]$ from which information is obtained about the drop of electrical potential across the diffuse component of the electric double layer. At the critical electrolyte concentration for deflocculation the potential drop is nearly the same for the four cations, and considerably greater than would be obtained from electrophoretic measurements using Smoluchowski's equation, which is evidently inaccurate under these conditions.

The work has been extended to mixed ions systems, particular attention being given to Na/Ca systems. It has been shown that the concentration of the equilibrium solution, which is critical for deflocculation, can easily be spotted visually. This concentration characterizes the tendency of the soil to deflocculate and is much easier to determine than the percentage of sodium amongst the exchangeable ions upon which this characterization has hitherto been based. For practical purposes this critical concentration can be obtained with sufficient accuracy by measurement of electrical conductivity, which is very rapid. If the chemical composition of the irrigation water is known, the degree of stability for the soil structure under irrigation can be predicted, and corrective measures devised when necessary. In this way control can be exercised at much lower cost than would be required to operate a system based on the estimation of exchangeable sodium by chemical analysis.

Colloidal studies in kaolinite suspensions

Mr. H. R. Samson has undertaken a fundamental study of deflocculation with special reference to kaolinite. Viscometric measurements on kaolinite suspensions show that even in very low electrolyte concentrations and with Na^+as the sole exchangeable cation, the suspensions remain flocculated.

In this respect, kaolinite differs from other clay minerals, which form colloidally stable dispersions under these conditions. It is found that the addition of a small amount of alkali, or a negatively charged polyelectrolyte, e.g. polymetaphosphate, sulphonate or alginate, is required to deflocculate the kaolinite.

In order to investigate the charge distribution on the kaolinite platelets, measurements of cation exchange capacity and of buffer properties over a wide pH range are being carried out.

CHEMISTRY DEPARTMENT

By E. M. Crowther

Fertilizer Investigations

Supplies of sulphuric acid for the manufacture of superphosphate and other fertilizers are likely to be restricted for several years by the world shortage of elemental sulphur. In many countries renewed interest is therefore being taken in alternative methods for converting rock phosphate into a more active fertilizer and in finding conditions in which superphosphate might economically be replaced by other materials. In the United Kingdom fertilizer prices rose very steeply on July 1, 1951 through the combined effects of removal of subsidies, shortage of sulphur and higher prices for other imported raw materials. Towards the end of 1951 a new subsidy was announced for phosphate fertilizers only. These changes in supplies and price structure may have marked effects on fertilizer practice. It is well known that many farmers use fertilizers at heavy rates as part of a long-term investment programme, whilst others, especially on inherently poorer soil, use far too little. There is an urgent need for more field information on alternative forms, amounts and methods of application of the main fertilizers and on means of estimating the relative requirements of various crops and kinds of soils.

Phosphate fertilizers

The Ministry of Supply has published a series of reports by members of the Building Research Station and of this Department on the production and agricultural value of silico-phosphate, a fertilizer prepared by heating rock phosphate with sodium carbonate, sand and steam. A further report on other alternatives to superphosphate is in the course of preparation.

During 1951 a new series of field experiments was initiated by the Fertilizer Conference of the Agricultural Research Council and organized by G. W. Cooke of this department. The field work was carried out under the direction of the soil chemists of the National Agricultural Advisory Service and by the staffs of the Northern Ireland Ministry of Agriculture, the Macaulay Institute for Soil Research and Rothamsted Experimental Station. One series of experiments on swedes and potatoes compared dicalcium phosphate, silico-phosphate and ground Morocco mineral phosphate, each supplying 0·5 cwt. P_2O_5 per acre, with superphosphate supplying 0·33 cwt. and 0·66 cwt. P_2O_5 per acre. The two rates of superphosphate, which were included to indicate the sensitivities of the tests, showed, as many earlier experiments had done, that quite small dressings often suffice to give good crops. The obvious adjustment to current shortages and prices is to reduce the amount of phosphate in fertilizer dressings on land with appreciable residues from past treatments but to make sure of adequate supplies on the more deficient soils.

On the average of thirteen potato experiments in 1951 dicalcium phosphate behaved very well, giving yields equalling those from superphosphate at the higher rate. Silico-phosphate, as in the

earlier series of field experiments, was less effective than equivalent superphosphate, giving mean yields close to those from the lower rate of superphosphate. As was to be expected, ground mineral phosphate was much inferior to superphosphate. For swedes dicalcium phosphate gave yields close to those from equivalent superphosphate; silicophoshate and mineral phosphate gave slightly lower yields. This series of experiments will be extended to new centres in 1952. The first year's results are, however, of interest in showing that, under conditions still to be defined more precisely, good results may be expected from some fertilizers in which the phosphorus is not soluble in water.

A second series of experiments tested so-called " Nitrophosphates." These fertilizers are made by attacking rock phosphate with nitric acid and then adding ammonia to produce a mixture of dicalcium phosphate and ammonium nitrate, but there is a large variety of alternative products according to the steps taken to reduce the proportions of calcium nitrate in the final mixture. In one process some of the calcium nitrate is removed before adding ammonia. In another ammonium sulphate is added before the ammonia in order to form calcium sulphate. The physical and chemical properties of the final product may be materially influenced by what at first sight may appear to be details of chemical engineering. The rate at which phosphate diffuses in the soil may depend on the surface area of the dicalcium phosphate exposed and on the amount and form of the other calcium salts present. Two kinds of " Nitrophosphate " were compared in field trials against superphosphate and a nitrogen fertilizer, which were tested separately and together. In six experiments on grass cut for hay there were clear responses to the nitrogen fertilizer but not to superphosphate. In these experiments the two " Nitrophosphates " gave similar yields which were slightly higher than those from superphosphate and " Nitrochalk." In the four experiments which gave good responses to superphosphate, two " Nitrophosphates " behaved differently, the one prepared by removing excess calcium nitrate giving better yields than the one prepared by incorporating ammonium sulphate. The two materials had markedly different physical properties; the first consisted of angular flakes, which readily broke down in water, and the second of hard large granules, which retained their form when wetted. It is possible that the phosphate from the first form became more quickly accessible to plant roots. Recent field experiments by the Tennessee Valley Authority on somewhat similar materials have shown that small granules (between 20 and 50 mesh sieves) were more active than larger ones. The British results are preliminary ones from a small number of experiments but, like the American ones, they suggest the physical form of fertilizers containing dicalcium phosphate may be of great practical importance. Granulating less soluble materials introduces quite different problems from those involved in granulating mixtures containing superphosphate or ammonium phosphate.

On the average of eight experiments on potatoes both " Nitrophosphates " gave slightly lower yields than equivalent superphosphate and ammonium sulphate.

Fertilizer placement

The efficiency of fertilizers may sometimes be markedly increased by placing them in bands near, but not too close to, the seeds so as to secure the benefits of high initial concentration of nutrients for the young plant. A series of field experiments on row crops was continued by G. W. Cooke and F. V. Widdowson in 1951 for a final year. The results of experiments over several seasons are summarized below. A granular PK fertilizer was placed in a band about two inches to the side of the seed and three inches below the soil surface and compared with equivalent dressings broadcast either at an early or a late stage in preparing the seed-bed.

	No. of expts.	Unmanured yield cwt. per acre	Increase in yield in cwt. per acre from		
			Broadcasting fertilizer	Early over late broadcasting	Placing over broadcasting
Threshed peas					
1947 ..	3	13·2	0·3	—	2·8
1948 ..	5	12·6	1·3	0·8	2·2
1949 ..	6	13·7	0·3	0·0	1·2
1950 ..	3	16·1	1·0	−0·3	1·2
Green peas					
1949 ..	1	76·6	5·5	−2·9	19·5
1950 ..	3	83·8	1·2	1·5	13·0
1951 ..	3	58·5	3·8	9·9	2·2
Winter beans					
1950 ..	3	18·0	1·5	0·9	1·1
1951 ..	6	16·2	1·5	0·0	0·9
Spring beans					
1949 ..	3	13·5	0·1	1·3	1·3
1950 ..	4	19·0	0·8	1·8	2·2
1951 ..	3	15·4	1·0	0·0	0·1

In 1951 early and late dressings of broadcast PK fertilizer (14 per cent P_2O_5, 14 per cent K_2O) gave similar yields of winter and spring beans. For peas picked green, early dressings ploughed in gave much higher yields than dressings broadcast on the seed-bed. Placing fertilizer in a band beside the seed gave higher yields of winter beans and green peas than broadcasting the same dressing, but in 1951 spring beans gave similar average yields from broadcast and placed fertilizer.

On the average of all experiments over four seasons, placing fertilizer beside the seed gave higher yields than broadcasting for each of the crops. The use of suitable drills should therefore prove profitable to farmers growing appreciable areas of these crops. In some seasons early dressings of broadcast fertilizer worked deeply into the soil gave higher yields of beans and peas than late dressings harrowed into the seed-bed. Where special placement drills are not available farmers are advised to broadcast fertilizer for peas and beans before cultivating to prepare the seed-bed; when possible, the broadcast dressings should be ploughed in.

G. W. Cooke and F. V. Widdowson carried out experiments in 1950 and 1951 on permanent pasture, leys and sainfoin to compare a granular PK fertilizer applied broadcast with the same dressing

applied in bands three inches below the soil surface, and generally about 10 inches apart. The fertilizer placement drill built for row crops was used to apply the fertilizer in bands. Broadcast fertilizer gave more hay than banded fertilizer in six out of seven experiments, the difference being significant in four experiments. The advantage of supplying nutrients fairly uniformly to all plants in a sward outweighs any disadvantage there may be in having the fertilizer on the soil surface. At most centres cutting grooves with the fertilizer coulters slightly reduced yields on plots without added fertilizer, but even where the " cultivation effect " was negligible on unmanured plots broadcasting still gave better yields than banding. Two experiments were made on lucerne drilled in the spring of 1950 with the row-crop fertilizer placement drill, testing a granular PK fertilizer (10 per cent P_2O_5, 20 per cent K_2O). At one centre with high yields and low fertilizer responses the first cut in 1950 gave significantly better yields from broadcasting than from banding, with no differences in subsequent cuts over two seasons. In the second experiment there were large and equal responses by the two methods. Dressings applied half in 1950 and half in 1951 were slightly inferior to those given wholly at sowing. Since lucerne develops an extensive root system it is able to use broadcast fertilizers effectively.

G. W. Cooke, M. V. Jackson and F. V. Widdowson carried out fourteen experiments on potatoes in 1951 using a simple potato planter with a fertilizer attachment made by the National Institute of Agricultural Engineering. National Compound No. 1 (7 per cent N, 7 per cent P_2O_5, 10·5 per cent K_2O) was applied in the following ways:

Broadcast on the seed-bed immediately before planting.
Placed in front of the seed-shoe of the planter.
Placed in contact with the seed.
Placed in one band beside and below the level of the seed.
Half the dressing broadcast and half placed in contact with the seed.

In all the experiments the machine worked on flat land, planting the potatoes and covering them over with a ridge of soil. When fertilizer was broadcast or placed in front of the seed-shoe its position within the ridge varied according to the condition of the seed-bed. With soil of " average " texture and moistness fertilizer applied by either method was thrown to the middle of the ridge and concentrated above the seed. With very wet soil much of the fertilizer remained on the outer surface of the ridge, but when the soil was very dry fertilizer was deposited beneath the seed.

On the average of all experiments broadcast fertilizer and fertilizer placed before the seed-shoe gave similar yields for both rates of application. Fertilizer placed in contact with the seed gave slightly higher mean yields than fertilizer drilled in bands beside the seed, and both methods gave much higher yields than broadcasting fertilizer or placing it in front of the seed-shoe. Placing half the fertilizer in contact with the seed and broadcasting the remainder gave somewhat lower yields than placing the whole dressing in contact, but the method was much superior to broadcasting all the

fertilizer. Placing fertilizer gave consistently higher yields than broadcasting; fertilizer in a side-band gave higher yields than broadcast fertilizer at twelve of the fourteen centres and higher yields than fertilizer before the seed-shoe at eleven centres. Emergence and early growth was generally checked by heavy dressings of fertilizer placed in contact with the seed. Later in the season the crops on these plots recovered at most centres. In assessing the value of contact placement it should be remembered that in 1951 the seed-beds were wet and there was ample rain in May with low temperatures in May and June. The experiments will be continued to determine whether the method is safe under other weather conditions. Until further results have been obtained, growers having planters fitted with fertilizer attachments are recommended either to modify their machines so that fertilizer is placed in a band beside the seed or to split heavy dressings, applying half in contact with the seed and broadcasting the remainder.

Rates of action of nitrogen fertilizers

Reserves of soil organic matter, crop residues and bulky organic manures owe some of their special merits in soil fertility and crop production to the slow liberation of ammonia and other plant nutrients. It is, however, singularly difficult to distinguish between these nutritional effects and others brought about more indirectly by changes in the physical properties or the micro-flora of the soil. The general problem might be simplified if it were possible in field experiments to employ suitable nitrogen fertilizers to produce ammonia slowly at rates comparable with those from bulky manures but without the associated indirect effects. Slowly-acting nitrogen fertilizers might also prove useful in practice for certain horticultural crops and for other purposes in which it is undesirable or inconvenient to give repeated small dressings of rapidly acting nitrogen fertilizers. Slowly-acting nitrogen fertilizers are, however, very difficult to prepare. Some of the materials favoured by horticulturists, such as dried blood or crushed hoof and horn, liberate their ammonia fairly rapidly in moist warm soil. In field and pot experiments in several years we have found that a plastic waste, formalized casein, acts much more slowly than crushed hoof and may give greater aggregate yields. In a pot experiment on repeatedly cut perennial ryegrass, set up early in 1950 and continued until the summer of 1951, formalized casein falling between 1 mm. and 2 mm. sieves gave about the same yields as crushed hoof (either 1-2 mm. and 5-6 mm.) in the first six cuttings but nearly twice as high yields in the next ten cuttings. Coarse formalized casein (5-6 mm.) naturally gave lower early yields, but the later yields were similar to those from finer fractions. The rate of action of crushed hoof was markedly slowed down by treating it with formalin, the fine fraction of formalized hoof being about as active as the coarse fraction of the formalized casein. Attempts have been made in the United States and in the United Kingdom to prepare slowly-acting forms of nitrogen fertilizer synthetically from urea and formaldehyde. Some of these products are relatively inactive, but the best of a series proved to be rather more rapidly-acting than fine hoof between 1 mm. and 2 mm. sieves. No sample proved more active

than fine hoof in the later stages of the pot experiments. Several other methods of retarding the breakdown of hoof and other proteins have been tested but so far no product has yet been found to equal formalized casein in steadiness of action and aggregate effect over long periods. Formalized hoof may have special merits where little immediate benefit is wanted.

In pot experiments conducted in 1951 the cuttings were arranged so as to give fairly steady yields per cutting from pots receiving constant amounts of urea after each cut. Other pots receiving all of their nitrogen initially in organic forms were cut at the same times. Under these conditions coarse and fine hoof and several urea-formaldehyde preparations had passed their peak yield by the fourth cutting. Fine formalized casein gave its peak about the sixth or seventh cutting. Coarse formalized casein and formalized hoof continued to give increasing yields up to about the tenth cutting but the yields from formalized hoof throughout were much below those from formalized casein. Fairly steady yields over all cuttings were obtained from mixtures of untreated hoof with formalized hoof.

In each of three seasons the pot experiments on repeatedly cut grass included a standard series in which varied quantities of urea were given periodically, the rates of application being changed at intervals to provide the factorial combinations of low and high rates early with low and high rates late in the season. In each season it was noted that the responses to heavy late nitrogen were less from pots with heavy early nitrogen. This suggests limitation by what is commonly termed " pot-binding," but in some of the experiments the maximum yield from the heaviest combination of urea dressings was less than those from some of the organic manures used at much heavier rates. It did not appear that the urea pots had reached any absolute limit, but that in some way the large early growth produced by abundant available nitrogen interfered with the efficient use of later nitrogen supplies. Such a state of affairs is well-known in manuring pastures or grass crops intended for silage or drying. The spring flush from early fertilizer dressings may lead to lower yields later in the year. This is commonly ascribed to the clovers being crowded out by the extra growth of grass, but there may be an additional factor. Where moisture and temperature allow, grass normally yields up to the limit set by the supply of available nitrogen. The top growth is accompanied by a more or less proportionate growth of root material of very low nitrogen content. When the tops are removed available nitrogen is used in rotting away cellulose from the roots and in consequence leaf growth may suffer through lack of sufficient nitrogen. Pastures and cut grass may show the field equivalent of " pot-binding." Additional nitrogen from fertilizers, urine or clovers may be needed to maintain mid-season growth and counter-balance the effects of the early flush. It may be partly for this reason that it is commonly recommended that old pasture and leys should be grazed heavily to give " a urine-soaked seed " before being ploughed up. In many parts of the world it is well-known that cereals and grass leys leave soils deficient in available nitrogen.

Nutrition problems in forest nurseries

Investigations in collaboration with the Research Branch of the Forestry Commission, reviewed over the period 1945 to 1949 in the Rothamsted Report for 1949, were continued. B. Benzian was in charge of the field experiments at six nurseries and several forests and R. G. Warren, H. A. Smith and J. E. A. Ogborn of the associated laboratory work. The Soil Microbiology Department co-operated in detailed soil examinations over three seasons at one of the nurseries. The wet seasons of 1950 and 1951 allowed good growth with striking responses to many kinds of treatment. Excellent first-year seedlings were obtained by appropriate treatments on very acid sandy soils taken over from heathland or conifer forest, and also on established nurseries of the agricultural type on which commercial production of conifer seedlings had to be abandoned as a failure. There are, however, a number of important theoretical and practical problems still to be solved before the new methods can be adopted generally. Conifer seedlings, especially of Sitka spruce, have proved very sensitive to a large variety of nutritional and other soil factors. They can be grown successfully in plots of one square yard, or even less, and it thus becomes possible to test on inherently poor soils many points beyond the present range of field experimentation on agricultural and horticultural crops. " Partial sterilization " by steam and formalin has given outstanding successes in the older nurseries, and a clear analysis of its mechanism may reveal factors of general interest in soil fertility studies.

The application of formalin at the rate of 250 ml. per square yard, suitably diluted, a month, or even several months, before sowing, consistently improved growth in all experiments on neutral or moderately acid soils which had been used as nurseries for many years. There have also been benefits in some experiments in newer nurseries with very acid soils. Good results have been obtained from the solid polymer, paraformaldehyde, but the best conditions for this material may not have been found, since it has occasionally proved less effective than formalin. Attempts are to be made in 1952 to inject neat formalin, as a step towards possible mechanical application. Apart from steam, acidification and repeated top-dressings of ammonium sulphate, no other treatment has given improvements at all approaching those from formalin. A variety of fungicides and the heavy urea treatment used successfully in the south-east United States for tobacco seed-beds have failed for conifer seed-beds in our experiments. The effects of formalin are difficult to analyse because profound changes are brought about in the soil flora and fauna. Formalin destroys most of the common soil fungi, checks nitrification and alters numbers of many kinds of micro-organisms for long periods. In some experiments formalin has reduced the numbers of plants destroyed by cockchafer and, in observations by B. Goodey of the Nematology Department, reduced the numbers of eelworms on or around the roots of Sitka spruce. Steam and formalin treatment still show some residual effect in a second Sitka spruce crop, sown in the following year. Drastic soil acidification may have more prolonged residual benefits, though there is a risk of damage in the year of treatment. In an experiment continued for three years at Ampthill Nursery, Bedfordshire, the

benefits from steam and formalin treatments given in February 1949 were outstanding in the first and second crops but had disappeared in the third crop; treatment with dilute sulphuric acid destroyed the crop in the 1949 drought but showed good effects in 1950 and still gave some improvement in the poor crop of 1951.

One-year seedlings of Sitka Spruce

	Mean height in inches		
	1949	1950	1951
Untreated	1·1	1·3	0·9
Steam	2·5	1·7	0·7
Formalin	2·1	1·8	0·8
Steam+formalin ..	2·6	2·0	0·8
Acid	failed	2·0	1·0
Steam+acid ..	failed	2·8	1·1
Standard error	±0·13	±0·11	±0·04

Some of the chemical results of the microbiological changes induced by steam and formalin applied early in March 1950 in an adjoining experiment at Ampthill Nursery are shown by the following data for the averages of soil samples taken on six occasions from April 4th to July 31st 1950. The soils were analysed soon after sampling and again after incubation for fourteen days at 25°.

	Nitrogen in parts per million dry soil				CO_2 production	One year Sitka spruce seedlings
	Field soils		Incubated soils			
	as NH_3	as NO_3	as NH_3	as NO_3	in parts per million soil	Mean height in inches
No treatment	4	7	2	17	186	1·8
Formalin ..	8	6	11	11	250	2·9
Steam ..	15	10	20	11	260	2·8
Both ..	14	6	16	7	252	3·0
					Standard error	±0·11

" Partial sterilization " increased the ammonia contents of the field soils and the carbon dioxide production on incubation. After incubation the treated soils had much more ammonia and less nitrate than the untreated ones. Many of the effects observed in several nurseries and seasons could be explained on the assumption that Sitka spruce seedlings grow better with ammonia than with nitrate. Repeated top-dressings of ammonia sulphate have given much better results on Sitka spruce seedlings than equivalent dressings of " Nitro-chalk " in several old forest nurseries. On the light soils commonly used for forest nurseries the pH values can be appreciably reduced in this way, at least for some months. It is possible that continued use of ammonium sulphate, together with the other fertilizers needed, may restore some " worn-out " soils to productivity. By contrast, it may be necessary on light soils used for agricultural and horticultural crops to pay careful attention to the acidifying effects of the large quantities of ammonium sulphate now being used, especially in compound fertilizers.

Some of the older forest nurseries have revealed an irregularity which might sometimes be overlooked in agricultural soils. There may be enough fragments of calcium carbonate to give abundant effervescence with acid in a field test, and yet the pH values, as measured by indicators or the glass electrode, may be as low as 5·5.

Agricultural and horticultural methods permitting a wide choice of cultivated crops normally maintain fairly high pH values and thus favour the rapid conversion of ammonia to nitrate. It has been suspected for several years that the failure of similar methods in forest nurseries was associated in part with the undue use of liming materials and calcareous manures or seed-covers. In experiments at several nurseries on very acid soils the growth of Sitka spruce seedlings has been seriously reduced by treatments with ground limestone or calcareous seed-covers, and at several other nurseries, which had been overlimed, growth was improved by acidifying the soil. At one nursery both kinds of change were effected experimentally within a single experiment.

Although on acid soils fertilizers have generally given as big or bigger seedlings than composts, the plants treated with fertilizer have sometimes shown discolourations suggesting some deficiency or other nutritional disturbance. Discoloration of the tips of the youngest needles following nitrogen top dressings in midsummer have recently been identified as a symptom of potassium-deficiency. A yellow discoloration and hardening of the upper needles late in the season, on plots with phosphate and potassium with late supplies of ammonia has been identified as a symptom of magnesium deficiency and controlled by supplying either magnesium sulphate or dolomite in preparing the seed-beds. To indicate the sensitivity of Sitka spruce on light soils it may be mentioned that in one experiment in an old nursery on moderately acid light sand the application of high-calcium or dolomitic limestone at the rate of 15 cwt. per acre reduced growth; the dolomitic limestone controlled the yellow symptoms but the high calcium limestone did not.

The Forestry Commission has attached great importance to the use of composts and rotational green crops for maintaining soil fertility, especially in the new heathland nurseries, but from the current investigations there appears to be little justification for heavy expenditure on composts for forest nurseries. Thus, in seventeen out of twenty-three comparisons in 1950 fertilizers gave slightly larger plants than composts. No consistent difference has been found in the subsequent behaviour in forests of seedlings or transplants raised with compost and fertilizers respectively. In rotation experiments at two centres with results over three seasons there has, so far, been no consistent improvement by interrupting a series of continuous seed-beds for a season under green crops or leys. The technique of small plot experimentation in forest nurseries has now been developed to the point at which it has been found feasible to start in 1951 two new series of rotation experiments (with suitable precautions to prevent the spread of soil between plots) to measure the long-term effects of altering the organic matter contents of light soils subjected to intensive cultivation. If the experiments succeed, they should in time provide interesting soil samples for studying the effects of cultural conditions on soil organic matter.

Soil Investigations

Soil organic matter

J. M. Bremner has extended his previous work on the chemical

nature of soil nitrogen by studying the acid-insoluble (i.e. humic) fractions of alkali and pyrophosphate extracts of soils previously examined without preliminary fractionation. Determinations by the highly specific ninhydrin method of the amounts of α-amino nitrogen liberated by acid hydrolysis of these humic preparations have shown that at least one-third of humic nitrogen is in the form of protein. The amino-acid composition of this protein material has been studied by the paper chromatography technique and the following amino-acids identified: aspartic and glutamic acids, serine, threonine, hydroxyproline, proline, arginine, histidine, lysine, phenylalanine, leucine, isoleucine, alanine, valine, glycine, tyrosine, β-alanine, α-amino-n-butyric acid and δ-amino butyric acid. Two unidentified ninhydrin-reacting substances and the oxidation products of methionine and cystine (or cysteine) have also been detected.

In the course of this work it was found that 10-15 per cent of the nitrogen present in the humic fraction of soil extracts could be accounted for as amino-nitrogen by the Van Slyke nitrous acid method. Since it appeared unlikely that such a large proportion of the humic nitrogen of soil is in the form of free amino groups, the effect of nitrous acid on substances likely to be present in soil extracts was investigated. It was found that nitrogen is evolved when lignin is treated with nitrous acid under the conditions employed in the Van Slyke method of analysis and that the reaction between lignin and nitrous acid leads to a large increase in the nitrogen content of the lignin. For example, a sample of wood lignin, containing 0·11 per cent N, was found to contain 2·5 per cent nitrogen after treatment with nitrous acid. Only 30-40 per cent of the nitrogen fixed by lignin in the reaction with nitrous acid is removed by strong acid hydrolysis. Most of this hydrolysable nitrogen is in the form of ammonia.

In continuation of the work described in the 1950 Report an attempt was made to follow the alkaline decomposition of threonine, serine, cystine and cysteine quantitatively. Results obtained in duplicate experiments were found to be inconsistent although recovery of the products of decomposition was practically quantitative. It is concluded that these alkaline decompositions are catalyzed by material dissolved by the alkali from the glass reaction vessels.

Earlier work in conjunction with R. H. Kenten of the Biochemistry Department on the paper chromatography of amines was completed and prepared for publication. This work involved the determination of the R_F values of a large number of amines in various solvents. Ninhydrin was found to be an effective spray for the detection of primary aliphatic amines on paper chromatograms. The results obtained suggested that amines likely to be present in biological materials could be separated and identified by paper chromatography.

Soil phosphorus

J. B. Rickson used the radiotracer technique to follow the exchange of phosphate ions between solution and solid in aqueous suspensions of calcium phosphates. It was possible to distinguish

between two kinds of exchange. A rapid one, generally complete in a few hours, probably represents an exchange on the surfaces of the particles; a much slower one may be due to pseudo-diffusion or recrystallization within the solid. Dicalcium phosphate showed only the rapid process, the total amount of exchange being equivalent to about 2 per cent of the total phosphorus present. Laboratory preparations of more basic calcium phosphates showed much higher rapid exchange and considerable slow exchange. The extent of both processes was reduced as the preparations were aged. Of the three rock phosphates, Curacao, Naura and Florida, the rapid exchange was least for the Curacao phosphate and the slow exchange greatest for the Florida phosphates. In similar experiments with North African phosphates it was necessary to add a little ammonium sulphate to obtain measureable amounts of water-soluble phosphate. Under these conditions the total exchange was appreciable and the first surface exchange continued for a much longer period with the Gafsa phosphate than with the other materials tested.

Analytical

Exhaustion land, Hoosfield

An account was given in the Rothamsted Report for 1949 of the history of plots which showed striking residual benefits in that season from farmyard manure or superphosphate applied in annual dressings for many years up to 1901, with none subsequently. The yields and total phosphoric acid contents of the 1949 barley crop were given in the Rothamsted Report for 1950 (p. 43). As 1949 was a drought year, it was possible that some of the striking long-term residual effects in that year might have been due to a stimulus to early root development from quite small additional supplies of available phosphate at a critical period. The 1950 season presented a marked contrast in weather, being much wetter. Comparable crop data for 1950 are given below.

		1950 *Barley crop* (*cwt. per acre*)		
	Manuring to	Dry matter		P_2O_5 in total
Plots	1901	Grain	Straw	crop
1, 2	None	11·0	15·2	0·104
5, 6	Nitrogen only	11·4	13·6	0·098
7, 8, 9, 10	Superphosphate	20·9	22·4	0·206
3, 4	Farmyard manure ..	22·2	24·0	0·243

In the wetter season the plots without residues from superphosphate or farmyard manure yielded better than in the dry season, but in both seasons the crops on plots with residues from superphosphate or farmyard manure contained about 0·1 cwt. P_2O_5 per acre more than the crops on plots without these residues. The manurial residues trebled the total phosphorus content of the crop in the dry year and doubled it in the wet one. The results for the two seasons show that a small fraction of the phosphorus in fertilizers and farmyard manure may remain available to crops over very long periods and that the aggregate recovery of phosphorus over long terms may be much higher than is commonly assumed from experiments over one or two seasons.

Figures given in the Report for 1950 showed that one of the plots (7-1) in the Hoos Permanent Barley experiment still contained appreciable residues of organic nitrogen from annual applications of farmyard manure from 1852 to 1871, with none since. Data are given below for citric-soluble phosphoric acid and potash from a detailed examination by R. G. Warren of soil samples taken in 1946 from all plots in this experiment.

Hoosfield Permanent Barley Plots

Annual Manuring since 1852

Series C Rape cake
AAS Sodium nitrate and sodium silicate
AA Sodium nitrate
A Ammonium sulphate
O No nitrogen

Strip 1 None
2 P as superphosphate
3 KNaMg as sulphates
4 PKNaMg

Series	Strip	citric-soluble P_2O_5 mg. per 100g. soil				citric-soluble K_2O mg. per 100g. soil			
		4	3	2	1	4	3	2	1
		PK	K	P	O	PK	K	P	O
C		76	10	96	12	30	31	5	6
AAS		78	7	103	8	32	33	3	4
AA		65	6	91	6	31	31	3	6
A		61	3	92	5	26	31	3	4
O		86	5	98	5	32	34	4	5

Additional plots

		citric-soluble mg. per 100g. soil P_2O_5	K_2O
6–1	Unmanured	5	5
6–2	Coal ash	7	6
7–1	Farmyard manure 1952–1871, then unmanured	10	8
7–2	Farmyard manure annually	122	49

Plot 7-1 with farmyard manure for 20 years and then unmanured for 75 years showed appreciably higher citric-soluble phosphorus and potassium than the adjoining plot (6-1) unmanured throughout the whole period. The plot with 14 tons farmyard manure per acre annually had more citric-soluble P and K than the plots receiving inorganic fertilizers only. The addition of sodium silicate slightly increased yields and phosphorus uptake in the absence of added phosphate; it also increased the citric-soluble phosphorus in the soil on plots with added superphosphate as well as on plots without superphosphate. Some of the low values for citric-soluble phosphorus and potassium on Strip 4 may depend on the fact that from the commencement of the experiment this Strip had less calcium carbonate than Strips 1 to 3 and some of the plots in Strip 4 are now acid.

General

During 1951 J. B. Rickson, E. H. Cooke and A. H. Green resigned their posts and G. E. G. Mattingly, O. Talib-udeen and K. Shaw were appointed. J. B. Rickson took up a post in the fertilizer industry and A. H. Green one on plantations in the Solomon Islands. G. E. G. Mattingly will work on radiotracer methods, O. Talib-udeen,

who transferred from the Pedology Department, on physico-chemical problems of soil and fertilizer phosphates and K. Shaw on the nitrogen availability of soil organic matter and organic manure. A. C. Venn, who worked in the department for a year as a Colonial Office Scholar, was appointed to the South African High Commission Territories to initiate soil fertility investigations, starting in Basutoland. J. K. R. Gasser, another Colonial Office Scholar, spent a year in the Department. M. V. Jackson of the National Agricultural Advisory Service was seconded to the Department for two yeare to gain experience in field experimentations. C. P. Kirkland of the Forestry Commission was seconded to assist in the forest nursery experiments.

In the spring of 1951 E. M. Crowther made an eleven week tour of the eastern half of the United States with an E.C.A. grant to study soil fertility and fertilizer investigations. He held the posts of President of the Agriculture Section of the British Association for 1951, President of the British Society of Soil Science for 1951 and 1952 and President of the Fertilizer Society for the 1951-52 session. He was also appointed Chairman of the Scientific Sub-Committee of the Standing Advisory Committee under the Fertilizers and Feeding Stuffs Act 1926, and Chairman of the Soils Sub-Committee of the Committee for Colonial Agricultural, Animal Health and Forestry Research.

PEDOLOGY DEPARTMENT

By A. Muir

Mineralogical Studies

African soils

The study of the soils of the Kongwa groundnut area has been extended to cover the sand fractions and some work has been done on a group of soils from the Equatoria Province of the Sudan. The minerals found in the Kongwa soils are those normally developed in metamorphic rocks of the gneissose type. Species noted included the following:

amphibole, iron ores, garnet, kyanite, sillimanite, zircon, rutile, epidote, staurolite, tourmaline, biotite, quartz, feldspar.

The Sudan soils are representative of various stages in three of the four catenary groups that have been recognized by Dr. H. Greene. All appear to be derived from high-grade paragneisses or schists of the basement-complex, as all contain the mineral sillimanite.

A comparative study of two profiles from acid schist and hornblende—garnet-gneiss of the Archaean complex near Accra, Gold Coast, is in progress. The basic gneiss weathers to give a sandy clay soil characterized mineralogically by a quartz-garnet-montmorillonite assemblage, while the acid schist gives a sandy quartzose soil with smaller amounts of clay comprising both montmorillonite and kaolin.

Clay Mineral Studies

Techniques

During the year a four-window X-ray set for crystallography, based on the self-rectifying gas tube, has been completed by Mr. Dibley, mechanic to the department. This is a completely self-contained unit of low initial cost having an X-ray output corresponding to about 10-15 ma at 30-40 kv. Provision is made for very rapid interchange of targets. The tube normally gives a point focus by means of a hollow spherical aluminium cathode, but experiments have been carried out to determine the best shape of cathode for obtaining a true linear focus, should this be wanted.

This set was exhibited at the Conference of the X-ray Analysis Group of the Institute of Physics, held in Leamington Spa in April. Two similar sets are to be built for use in the Pedology Department and the Soil Survey.

Mention was made in last year's report of efforts that were being made to reduce X-ray exposure times. Further work on the problem has shown that there is a lower limit to the angle at which the powder camera axis may be set with respect to the target face, due to absorption of radiation in the target material itself. This is because the depth at which the X-rays are produced is appreciable—of the order of a few microns. The phenomenon is of importance only when a narrow beam is used. The observation is in fact a rediscovery of an early result, but it seems to have been lost from sight in recent years.

Electron diffraction

The electron diffraction patterns of montmorillonite obtained by Professor Finch have been indexed and calculations have been made of the intensity of diffractions to be expected from a normal beam photograph of a flake of montmorillonite. The atomic coordinates used were those conditioned by a muscovite superposition of half-layers and the three possible arrangements of the octahedral aluminium ions were tried. All three arrangements gave fairly good agreement with the experimentally observed intensities. Other methods of super-position of the half-layers were used in subsequent calculations but agreement was not as good as with the muscovite super-position.

Calculations were also made of the distributions of intensity across several (hk) bands, again based on the atomic coordinates of muscovite. These bands were (11, 02) and (33, 06) and (19, 53, 46) and although the calculated band shapes agree very well with the observed shapes the positions of the maxima are displaced.

Quantitative determination of clay minerals

The theory of X-ray reflections given by oriented aggregates, which was mentioned in last year's report under this heading, and which has been developed further, was communicated to the 2nd International Congress of Crystallography in Stockholm, by K. Norrish and D. M. C. MacEwan. A detailed theory of the absorption of X-rays in powder specimens of different shapes has also been worked out. It is hoped to apply these theories to the quantitative determination of clay minerals in mixtures, using oriented specimens. This will be an advantage over the usual procedure of trying to obtain a completely unoriented specimen—always difficult of achievement, even if it were desirable. The results could also be applied to the determination of the degree of orientation of fibrous or flaky minerals in aggregates.

X-ray diffraction by inter-layer mixtures

Many clay minerals are composed of minute lamellae interstratified on a molecular scale, and they then give rise to diffuse X-ray reflections, and non-integral orders of reflection. It is of interest to have an X-ray technique for determining what components are present in such a case, and what their relative proportions are. This problem can be attacked by calculating a series of curves, using various assumed mixtures, which may be compared with the photographs actually obtained. Suitable curves for some commonly occurring mixtures have been published by G. Brown and D. MacEwan (see this Report for 1949, pp.152-153), and their usefulness was acknowledged at the International Congress of Soil Science (Clay Minerals Section) in Amsterdam last year, when it was suggested that they should be augmented by calculating a number of further cases.

A direct comparison of these theoretical curves with experimentally determined intensities in the case of a random montmorillonite-glycerol mixture has recently been made. It has been found that heating lithium montmorillonite to a comparatively low temperature reduced its sorption of organic liquids. Preliminary

X-ray photographs of previously heated lithium montmorillonite showed that the rate of sorption of glycerol was slow and could be controlled by heating. In this way samples with increasing amounts of sorbed glycerol could be obtained. The photographs also suggested that the glycerol was sorbed was the two-layer complex even at low sorption values and that these layers were randomly distributed. The Hendricks and Teller formula was applied to this case and X-ray diffraction patterns were obtained of samples which contained different amounts of sorbed glycerol. Comparison of the observed diffraction patterns and the intensity distributions obtained by calculations showed good agreement.

Sorption of organic molecules by montmorillonite

A study of the effect of intensive drying on the sorption of acetonitrile, nitrobenzene and pyridine was carried out. The results confirmed Glaeser's conclusion that the formation of " Normal " complexes can be inhibited. The results of later work suggested that the effect was in some cases due to a depression of the rate of interlaminar penetration.

The pyridine complexes of Li-, Na-, K-, montmorillonite were examined by differential thermal analysis, and it was found that the Li and Na clays gave complex low temperature peaks whereas K clay gave a simple peak. This was interpreted as indicating marked ion-pyridine interactions in the former case. Nitro-benzene gave a similar peak with Na- montmorillonite. In view of these complex peaks it was decided that a more detailed study of the work of Hendricks, Nelson and Alexander on the hydrates of montmorillonite was desirable. Detailed isobaric dehydration and hydration curves of Li-, Na-, Ca-, Mg-, montmorillonite and Li-hectorite were carried out. Great care was taken to establish equilibrium at each point, some points taking several days. The conclusions from this work were that differential thermal curves show differences in diffusion coefficient rather than changes in solvation energies and that definite hydrates are not formed in montmorillonite. Two further items of interest resulted. First, it was found that the apparent amount of structural water left after the mineral had apparently lost all of its sorbed water depended on the hydration energy of the exchange cation. K- montmorillonite gave 5·0 per cent hydroxyl water in agreement with the Hofmann structure. Secondly, hysteresis effects were observed on rehydration, being most marked with Li- montmorillonite. The unusual properties of Li- montmorillonite have been discussed in a note to the Clay Minerals Bulletin (in the press).

Owing to the desirability of obtaining less ambiguous information than was obtained in liquid studies (Rothamsted Annual Report, 1950), and some quantitative data on the energy changes on sorption, work was commenced on vapour phase measurements. The results confirmed that hysteresis is always present at room temperature when interlaminar sorption takes place. Rates of sorption studies on adsorption and desorption have been carried out in which the effect of varying the temperature, pressure, and coverage, on the rate coefficients was determined. The results suggest that the desorption isotherm is probably the best measure of the free surface

energy lowering of the sorbate, and that the main causes of hysteresis arise from the fact that work must be done to provide sorption sites in the mineral.

The desorption isotherm of water from Na- and K- montmorillonite has been measured in detail. Heats of desorption have been deduced using the Clausius-Clapeyron type equation and their variation with amount sorbed determined. The heats are less than those observed by workers on the zeolites and reach a maximum on the external surface.

The adsorption of pyridine and water on Na- montmorillonite has given data on the probable part played by the external surface during sorption. Good correspondence has been obtained between Escard's surface area by nitrogen adsorption on Na- montmorillonite and the amounts of adsorbate covering the external surface as deduced from isotherms.

Isotherms obtained with Na- montmorillonite flakes were similar to those obtained with alcohol flocculated powders except that the former seem to have a smaller external area.

The study of the interaction of amino-acids and proteins on montmorillonite has been concluded. Fixation of these molecules by the proton transfer mechanism previously described (Rothamsted Annual Report, 1950) was found to prevent the expansion of montmorillonite by the uptake of water or glycerol; even the smallest amino-acid showed this effect. Changes in the X-ray pattern of these complexes, as the size of the adsorbed molecule was increased from glycine to salmine (a large basic molecule of mol. wt. *ca.* 8,000), coupled with chemical determinations for N, showed the effect of the progressive filling up of the interlamellar space.

Two other mechamisms operate in the fixation of these amino-acid molecules in which the presence of the nitrogen compound does not prevent the expansion of the clay sheets with glycerol. Firstly, adsorption at the iso-electric point of the acid due to the dipole character of the molecule; and secondly, coordination with copper when this is the base exchange cation. These complexes are very labile.

The fixation of proteins, which form insoluble salts with base exchange cations e.g. Ca-edestin, Zn-insulin, showed characteristics which suggest that precipitation of these salts occurs at the edges of the interlammelar space rendering the clay inert to water and glycerol expansion. For stability, this compares favourably with the first type of complex.

Clay mineralogy of rocks and soils

Palygorskite. A specimen of a white to yellowish white fibrous material found in pockets in weathered granite in the Shetland Isles has been found to consist of the mineral palygorskite associated with minor amounts of montmorillonite. Further work on this material and on palygorskites from other British occurrences is in progress.

Glauconite. Work was commenced during the year on the weathering of the mineral glauconite, and soil profiles overlying highly glauconitic materials of the Upper Greensand and Brackle-

sham Beds were collected. Owing to the resignation of Mr. I. L. Freeman from the Soil Survey this work has been suspended.

Lepidocrocite. In several soils from the north of England investigated during the past year, lepidocrocite γ-hydrous ferric oxide, has been found associated with the orange mottling which is prominent in gleyed soils. An attempt is being made to separate the red iron oxide which occurs in what seems to be a pure condition from the dead root channels of a gleyed horizon with a view to characterizing it by X-ray diffraction.

Lancashire boulder clays. An investigation of several different types of boulder clays has been made with a view to differentiating the drifts which form the parent material of many of the soils in England. There were no striking differences between the samples studied, the main constituents being illite, kaolin and chlorite. It is possible that a detailed examination of each type may enable the drifts to be identified by the minerals present in minor amounts.

Black cotton soils. The clays from a group of soils of this type from India, Nigeria, Gold Coast and Southern Rhodesia, examined on behalf of the Road Research Laboratory, proved without exception to contain a montmorillonoid as the dominant clay mineral, with minor amounts of kaolin and illite. In the case of a dark valley soil from Kongwa little or no montmorillonoid is present in the clay, the main constituents being illite and kaolin. It is possible that this soil may be derived from a recent limestone.

Spectrographic Work

The investigation of the trace element content of soils continues with particular reference to those derived from the Lower Lias. It would appear that the bulk of the Mo, V, Co, Ni and Cr in these soils resides in the clay fraction, though not in the alumino-silicate clay minerals. Further investigations are proceeding with a view to establishing what factors involved in controlling the distribution of trace elements in such soils derived from sedimentary deposits.

Investigations are being carried out on rice samples from Malaya, where it is thought that low yields may be due to trace element malnutrition and also on spruce trees for the Forestry Commission, where similar trouble is suspected.

For the routine determination of exchangeable cations in soils by the Lundegardh flame technique a method has been adopted whereby the ammonium acetate is allowed to percolate through the soil automatically. This gives results in good agreement with the standard filtration method and has the advantage that the exchange capacity is readily determined afterwards on the same sample.

Gleying in Soils

It has previously been reported that soil material may be gleyed in the laboratory by the action of anaerobically fermenting plant material. It has been found that despite the extensive reduction of the ferric oxide, the fermentation extract is capable of reducing further ferric iron provided this is in soluble form. In addition, the rate and extent of the gleying is decreased considerably if the ferric

oxide is previously subjected to moderate heating. This suggests that the overall rate of the process of gleying is determined by the rate of the initial solution of the ferric oxide. By comparing the progress of gleying and the production of acid and reducing compounds during the fermentation of different plant species it is hoped to obtain further information on this aspect of the problem. It has been found that the ferrous solutions obtained by fermentation of different plant species may vary considerably in their ease of oxidation. The extracts of some species, notably oak leaves, oxidize so readily that the preparation of samples for analysis is difficult. The choice of grass for the initial experiments was therefore a fortunate one.

It is known that the kauri (*Agathis Australis*) is exceedingly active in podzol formation, and its debris is said to give a very acid litter. Samples of kauri leaves and bark have recently been received from New Zealand and it is hoped that they will afford an easier approach to the problem of the initial solution of ferric oxide in the fermentation process.

Published accounts of the iron content of gley soils show that in certain cases gleying does not result in appreciable diminution of the iron content of the soil and it is difficult to reconcile these results with those of the fermentation experiments since in the latter there is an almost complete removal of the ferric oxide. It seems probable, however, that the previous workers examined the mottled type of gley soil, and that the analyses were made on bulk samples. The effect of small scale migration of iron would thus be obscured. In an attempt to resolve this contradiction, two types of gley soils have been examined:—

(1) a uniformly dark grey soil covered by 12 inches of acid peat and containing no roots;

(2) a soil showing extensive orange-red mottling on a pale grey background.

For (1) it was found that the iron content of the bulk samples increased slowly over the first twelve inches of the mineral soil—(from 0·5-0·8 per cent, expressed as Fe_2O_3), thereafter increasing more rapidly from 1·6 per cent at 16 inches to 3 per cent at 24 inches. In the case of (2) the total iron content of the bulk samples decreased fairly regularly with depth, falling from 10-13 per cent at the surface to 4-6 per cent at 3 feet. Analysis of hand picked samples of the grey and brown material showed that while the total iron content of the grey material remained essentially constant at 2-3 per cent, that of the brown mottles decreased slightly irregularly with depth from 17 to 8 per cent at about 3 feet. The free ferric oxide was in general roughly 2 per cent less than the total iron on both the grey and brown separates. It is significant that while root channels were absent from the soil under peat, which was not mottled, in (2) the iron-stained patches were always located around old root channels.

On the basis of these results it is suggested that soil (1) and the grey material from (2) represent the true end products of gleying, and correspond to the soil residues from the fermentation experiments. The iron staining in (2) represents an opposing tendency

which is associated, in this case at least, with some such factor as aeration or enhanced bacterial activity, which is in turn associated with the root channels. The essential constancy of the iron content of the grey material from (2) is surprising, since it might be expected that with increasing intensity of gleying a continuous decrease in the iron content would be produced in the gleyed soil.

Some, as yet unconfirmed, results obtained in fermentation experiments suggest that the grey colour of gley soils is caused by sorption of ferrous-organic compounds on the clay and it seems likely, therefore, that the 2-3 per cent " ferric oxide " of the grey separates represents the saturation value of this sorption complex.

A further result of this work is that the distribution of free alumina has been found to follow that of the free ferric oxide, i.e. the free alumina content of the brown patches is higher than that of the grey fraction.

SOIL MICROBIOLOGY DEPARTMENT

By H. G. Thornton

General Soil Micropopulation

Counts of micro-organisms in Broadbalk plots

The survey undertaken by Dr. Janet Brind, Mr. P. C. T. Jones and Mr. F. A. Skinner, in which direct microscope and plate counts were compared, is completed. Results have been analysed and a paper on the results is in the press and will appear in the Journal of General Microbiology.

Partial sterilization—Ampthill plots

Miss L. M. Crump has continued the sampling and bacteriological study of the Ampthill Forest Nursery plots, in collaboration with the Chemistry Department. Work this season was limited to a comparison of plots treated with formalin with untreated plots. The results confirmed those found in the two previous years in both of which the weather had been abnormal. In the treated plots maximum numbers of bacteria were found about eight weeks after the application of formalin, but numbers were still significantly higher than control more than six months after application. Qualitative differences were again found after formalin treatment particularly in increased numbers of denitrifying bacteria and in those resistant to formalin.

The study by Dr. Janet Brind of the effect on the fungal population of steam and formalin sterilization and of acid treatment of the Ampthill plots has been concluded and the results prepared for publication. The main findings were (1) the persistent effect of steaming in reducing the numbers of fungi, which, after initial elimination, had after two years, increased only to half the numbers of the control plots and (2) the early recolonization of the formalin treated plots by *Trichoderma viride* and its sustained dominance there. Many of the most frequently occurring fungi have been identified from the control plots, as well as the early recolonizers of the treated plots. Plating dilutions of soil samples from a second experiment on an adjacent area showed that the general reactions of the fungal population to steam and formalin followed the same general pattern both qualitatively and quantitatively. Laboratory experiment has shown that *Trichoderma viride* is more tolerent to concentrations of formalin than some of the other frequently occurring fungi.

Dr. B. N. Singh has followed the effect of the formalin treatment of the numbers of amoebae in these plots.

The persistent effects of partial sterilization on the soil microflora are clearly complex and, in analysing them, two possible actions of the sterilizing agent need investigation. One is the direct and specific elimination of certain groups of organisms followed by recolonization by organisms such as Trichoderma whose competitive ability, possibly aided by the production of antibiotics, prevents the re-establishment of the original micropopulation. The other is the possible change produced in the soil nutrients available to the microflora which may provide substances utilizable by specific

groups of organisms. Studies in different connection of antibiotic organisms are being made in the case of Actinomycetes and Myxobacteria and of the effect of specific nutrients in the case of bacteria attacking aromatic halogen compounds.

Actinomycetes antagonistic against Fungi

The question how far the antibiotic secretions of micro-organisms exert an effect on the equilibrium of the soil population and whether antibiotic organisms can be used to control root diseases, cannot be answered till we know more about the rate of production and persistence and activity of antibiotics in soil. An important cause of lost activity is absorption by the soil itself. This factor has been particularly studied in the case of antibiotic secretions of actinomycetes.

Mr. F. A. Skinner has continued work on the inhibition of *Fusarium culmorum* by a soil actinomycete. In particular, further investigations have been made on the absorption of the actinomycete antibiotic by clays and by solid organic materials. Tests made with liquid actinomycete cultures and culture filtrates have shown that absorption can be affected not only by bentonite but also by kaolin, samples of Rothamsted clays, lignin and precipitated humic material. Some humified materials can serve both as nutrient sources for the actinomycete and as absorbents for the antibiotic. There is some evidence to indicate that the addition of extracts of some naturally occurring organic soil materials to solutions known to contain the antibiotic enable *F. culmorum* to grow in these solutions.

Some preliminary experiments have been made to find out whether wheat roots have any stimulating action on the growth either of *F. culmorum* or on actinomycete antagonistic to it. No such stimulation has been recorded.

Decomposition of Aromatic Halogen Compounds by Soil Micro-organisms

The increasing use of organic halogen compounds for various agricultural purposes, makes a study of the persistence of such substances in soil of some importance. Experiments have been carried out by Dr. Norman Walker to investigate whether monochlorophenols can be attacked by soil micro-organisms and some work has also been done with monochlorobenzoic acids and 2:4-dichlorophenol. Three main experimental methods have been used ; the percolation of solutions of chlorophenols through a column of soil crumbs, using either the Audus type soil-percolator or a simpler modification of it which is easily sterilized, and employing a bromine-titration method for estimating the chlorophenol concentration ; attempts to secure enrichment cultures of soil bacteria capable of utilizing chlorophenols by using culture media in which the chlorophenol is the sole carbon source ; and finally, studies of the oxygen uptake of suspensions of likely bacteria in Warburg manometers using chlorobenzoic acids as substrates. Up to date, the chief results of this work has been to show that *o*-chlorophenol or *o*-bromophenol can be decomposed by biological means in soil. There is some evidence that *m*- and *p*-chlorobenzoic acids may be oxidized by a soil *corynebacterium*. No reliable evidence of the biological decomposition of p-chlorophenol or of 2:4-dichlorophenol

in soil has yet been obtained, and even if these compounds are attacked, they are, in any case, much more persistent in soil than *o*-chlorophenol. *p*-Chlorophenoxyacetic acid suffers some decomposition in soil under conditions of storage and there is evidence that enrichment of soil with appropriate organisms can be obtained by repeated treatments with increasing doses of this compound. A yeast species has been isolated from soil, which is capable of limited growth in a liquid medium in which phenol is the sole carbon source.

Reduction Processes in Soil

It was observed that some soils when incubated aerobically after treatment with carbon tetrachloride and the addition of a solution of sucrose and ammonium sulphate, evolved hydrogen sulphide. As the literature suggested that the formation of hydrogen sulphide from sulphate is due to obligate anaerobes this primary observation was extended to find if anaerobic sites were developing in the aerobically incubated soil. The results of this work indicated that hydrogen sulphide was evolved from soils of low buffering capacity against acid after the soil microflora had been modified by carbon tetrachloride, ether, chloroform or toluene. The hydrogen sulphide produced from the added ammonium sulphate in the experiments was not formed by anaerobic organisms but by an aerobic *Bacillus sp.* High concentrations of oxygen did not prevent the formation of hydrogen sulphide in soil. The conclusion is that hydrogen sulphide formation from ammonium sulphate in soil is not necessarily indicative of anaerobic conditions.

The carbon tetrachloride etc. inhibited the development of fungi. Antagonism on synthetic media between fungi isolated from the untreated soil and the above mentioned *Bacillus sp.* has not been observed although the fungus inhibits the evolution of H_2S by this *Bacillus* in soil.

The solution and reduction of ferric hydroxide by soil micro-organisms has been studied in an attempt to find out how an insoluble inorganic compound can be transformed into a form which may be suitable for plant uptake. A number of pure cultures of facultative anaerobic bacteria have been isolated which can reduce ferric hydroxide during the breakdown of sucrose. Reduction has been observed in cultures which have a final pH of 5·5. This work has been carried out by Mr. S. M. Bromfield.

Nitrifying Bacteria

Dr. Jane Meiklejohn has investigated the iron requirements of Nitrosomonas and the phosphate requirements of this organism and of Nitrobacter. She found that Jensen's strain of Nitrosomonas is stimulated by as little as 0·1 mg per litre of iron, the stimulation increasing with doses up to 6 mg per litre. The effect of iron shows itself even in the presence of other trace elements ; it is most marked in the early stages of cultural growth. In spite of the stimulating action of iron over the above dosage range, the minimal concentration essential for growth is less than 0·05 mg per litre. The phosphate requirements of both organisms are extremely small. Jensen's strain of Nitrosomonas has so far been passed through three serial transfers of medium lacking any phosphate.

Mycorrhiza

Dr. Janet Brind's study of the Mycorrhizal associations in clover and wheat roots was undertaken in order to obtain evidence bearing on the claim that such associations are beneficial to crop plants.

A comparison of the growth of clover plants with and without infection of their roots by the mycorrhizal fungus Rhizophagus but in a soil of similar microbiological flora has been possible by adding soil dilutions to a sterilized artificial soil medium. At a dilution of 1/5 pots with infected and uninfected plants were obtained, whose dry weights could be compared. A similar experiment was done on wheat. Only at the lowest dilution used (1/5) were some pots found with infected plants. A comparison of the dry weights of these plants with uninfected plants from replicate pots of the same dilution series showed no significant differences between the two series, with either clover or wheat. The results of this work thus offer no support to the view that clover and wheat receive benefit from association with the fungus.

Soil Amoebae

Work with soil amoebae has hitherto been handicapped by lack of systematic knowledge of or ability to identify the species of these organisms found in soil. Dr. B. N. Singh has completed his detailed study of the life history and nuclear division stages of nine species of soil amoebae and has proposed a new system of classification for the amoebae based on nuclear division. He has a paper on this subject in the press which will appear in the Philosophical Transactions of the Royal Society. In the course of the work he showed that serious errors exist in some previous descriptions of mitotic division in amoebae and that contrary to these descriptions, the course of mitosis closely resembles that normal in metazoa. He has also made a comparative study of the process of mitosis in the amoeboid stages of several species of Acrasieae.

Miss Lettice M. Crump has continued her investigation of the behaviour, particularly as regards excystment, of a number of soil amoebae, several of which require the presence of bacteria to enable their cysts to hatch.

Myxobacteria

Dr. B. N. Singh has continued his study of the physiology of species of Myxobacteria that feed by the lysis of certain species of Eubacteria.

Work on Nodule Bacteria Rhizobium and Leguminous Plants

This season's work has been mainly concerned with the action of legume root secretions on infection by Rhizobium. This comprises an investigation by Dr. P. S. Nutman of inhibitory action of a legume plant on the nodule formation of other legume plants growing near it and a study by Miss Hilary Purchase of the influence of the near presence of roots on the multiplication of Rhizobium in sand.

Plant interaction

Work on the mutual reduction of nodule formation on clover plants growing together has been extended to include a study of the interactions between species of legumes belonging to different cross-

inoculation groups and between legumes and non-legumes. Lettuce and flax were shown to be only slightly inhibitory (when growing in a medium containing no combined nitrogen) to nodule formation on clover, and to have no influence on the amount of growth made by the clover.

The cross-inoculation group relationships in plant interaction were studied using the following four species. *Trifolium pratense, Medicago sativa, Vicia hirsuta* and *Anthyllis vulneraria.* These were grown singly and in all combinations of pairs with either one or both host species receiving the appropriate strain of bacteria in the inoculum.

Nodule formation on clover was found to be uniformly reduced (to about half the number of nodules found in single plant cultures) by the presence of a second plant of any kind whether or not the companion plant was inoculated with its own strain of bacteria. Neither the number of roots formed on the clover nor its size, as determined by dry weight, was uniformly depressed by a companion plant of a different species. In most cases no effect was discernable and in one comparison, i.e. with uninoculated lucerne as companion plant, a marked and highly significant increase was observed in the number of lateral roots formed on the clover.

Clover was also distinguished from the remaining host species in causing a depression of infection rate, rooting and growth of all the other plant species when it was itself inoculated but it was without effect on the other species when unnodulated.

A further general result was the inhibition of nodule formation, rooting and growth of each species of host plant when grown in pairs with its own kind.

Among the other interactions no clear relationships could be deduced ; on the one hand lucerne was shown to be unaffected by the presence of uninoculated or inoculated *Vicia* whereas the rooting and growth of *Vicia* was stimulated by uninoculated lucerne and inhibited by inoculated lucerne.

The complex pattern of these interactions suggest that more than one inhibitory root secretion may be involved, the host species varying in their susceptibilities to these secretions. Preliminary tests by Miss Purchase have also shown that where two strains of bacteria are present in a culture, one may become dominant and the altered balance of the bacteria may affect the number of nodules formed.

Previous work has shown that the numbers of nodules formed on a clover root is affected by (1) the genetic constitution of the host (2) the character of the strain of bacteria used as inoculum (whether effective or ineffective in fixing nitrogen) and (3) the time at which the inoculum is added to the seedling culture (moderate delay with effective inoculation leading to an increased rate of nodule formation). Further experiments on the effect of these factors on single and paired plant cultures have shown that in all cases they act independently of inhibition.

Experiments with plants which have been selected for early or late primary infection have given clear evidence of differences in inhibition. Plants which form their first nodules early in seedling growth are more inhibitory to nodule formation of another plant,

than those which develop nodules late. This result might indicate identity between the inhibitor and the root secretion postulated by Thornton to be stimulatory to infection.

As yet experiments made with the object of concentrating the inhibitory principle or to elute it from chemical adsorbents added to the culture medium, have not been successful.

Growth of Rhizobium in the root surroundings

The depressing influence of root secretions on nodule numbers found by Dr. Nutman raised the question whether this could be in part explained by any depressing action that they might have in the numbers of bacteria in the proximity of the root. There is also the possibility that where nodule bacteria of types unable to infect the plant are also present these may be stimulated to increase in competition with the infective strain. To study these possibilities Miss Hilary Purchase carried out an experiment in sand culture with clover and lucerne, using three strains of bacteria from clover, two from lucerne and two from pea each added to sand with and without clover and lucerne plants. The presence of any host plant caused a rise in bacterial numbers regardless of whether the bacterial strain was capable of nodulating the particular plant species. The possibility of bacterial competition at the expense of the infective strain is thus not ruled out.

There was a larger rise in bacterial numbers in the immediate proximity than at a distance from the roots. This result thus does not suggest any harmful influence of root secretions on the bacterial population that might have accounted for the depression in nodule numbers found by Dr. Nutman. After an initial rise bacterial numbers remained constant till the end of the experiment (60 days).

Miss Purchase has also made a large number of serological tests of strains of clover nodule bacteria from various parts of Great Britain in connection with our study of their geographical distribution.

Formation of β-indolylacetic acid by Rhizobium

Previous work has suggested that the substance secreted by nodule bacteria that is responsible for the deformation of the host root hairs before infection, was β-indolylacetic acid. Dr. Norman Walker has found evidence that Rhizobium can in fact produce this compound, some strains producing it from *l*-Tryptophane, others from *d*-Tryptophane and others from both isomers.

Work on Rhizobium Bacteriophage

Rhizobium bacteriophage

Work on these phages has by now produced a considerable literature. This interest is due in part to the influence that they may have on nodule bacteria in the soil but also because the unusually slow process of infection and multiplication characteristics of these phages makes them particularly suitable material for the study of phage behaviour in general.

Previous work has shown that while with a young culture of Rhizobium a single phage particle may suffice to produce infection, the chance that it will do so decreases with the age of the bacterial

culture. It was thought possible that this might be due to some inhibitory action of the polysaccharide produced by the bacteria. A purified sample of this polysaccharide was prepared, but when diluted phage was plated with the bacteria in agar in the presence of 0·25 per cent of the polysaccharide the latter produced no decrease in plaque count as compared with a control to which no polysaccharide was added. Nor did this concentration of polysaccharide in liquid medium influence the plaque count when phage and bacteria were incubated in it for a few hours before dilution. Thus the reduced chance of infection with an old bacterial culture can scarcely be attributed to an accumulation of the polysaccharide. On the other hand with longer incubation of the phage and bacteria in liquid culture, the rate of phage multiplication was reduced by the presence of the polysaccharide regardless of whether this was obtained from the host bacterial strain or from a strain resistant to the phage.

Studies have also been made on the inactivation of Rhizobium phage by ultra violet light. No evidence was found that several irradiated phage particles could multiply in a bacterial cell where a single particle failed to do so, as has been reported with Coli phage. The effects of ultra violet light in inactivating the Rhizobium phage in a culture continue after the irradiation has been stopped, since phage thus exposed falls off in activity at a rate greater than that of phage not irradiated. The addition of phage inactivated with ultra violet light to an active phage culture of the same strain checks the multiplication of the latter in the host bacteria. There is complete inhibition for the first three to five hours of incubation at room temperature. The effect seems to be specific since very little inhibition is produced by the addition of irradiated phage of a different strain to which the bacteria are resistant. Rhizobium phage that has been inactivated with ultra violet light can be partially reactivated if a mixture of such phage with the host bacteria is exposed to visible light. This phenomenon of " photo reactivation " has been recorded with Coli phage and also with other biological material. This work with Rhizobium bacteriophage was carried out by Dr. J. Kleczkowska in collaboration with Dr. A. Kleczjkowski of the Plant Pathology Department.

BOTANY DEPARTMENT

By D. J. Watson

There were only two changes in the scientific staff during the year: Miss J. M. Patterson resigned, and Mr. S. A. W. French, who had served for more than 20 years on the assistant staff, was appointed Experimental Officer.

P. C. Owen and J. H. Wilson were awarded the Ph.D. degree of the University of London. Dr. Wilson returned to his post in the Department of Agriculture, Tasmania, in June.

Plant Nutrition

Micro-nutrients

Dr. K. Warington continued her investigations in solution culture on interactions between micronutrient elements (32). The chief objects were to determine (1) if iron-deficiency chlorosis induced by manganese excess can be offset by the addition of either molybdenum or vanadium and (2) if addition of molybdenum affects the sensitivity of oats to varying manganese supply. In the first series, molybdenum was provided at rates ranging from 0·1—20 p.p.m., but the upper limit of the range for vanadium was a rate equivalent to 10 p.p.m. Mo, because of the greater toxicity of this element. Molybdenum at 20 p.p.m., and to a less extent at 10 p.p.m., intensified chlorosis induced in soybean and flax by manganese excess (10-25 p.p.m.), though these concentrations were harmless in the presence of 1 p.p.m. Mn. Vanadium ($\equiv$1·0, 5 and 10 p.p.m. Mo) counteracted some of the symptoms of manganese toxicity, but the two higher rates were themselves harmful to growth irrespective of the level of the manganese supply. These toxic concentrations of vanadium at first deepened the green colour of the shoot, suggesting some alleviation of the iron deficiency, but apical chlorosis generally followed later. Low molybdenum (0·1 p.p.m.) or equivalent vanadium had no influence on growth or iron nutrition at either level of manganese. Visual differences were corroborated by changes in the nitrogen, phosphorus and iron contents of the plants. There was no evidence of replaceability of molybdenum by vanadium.

In the second series, oats were grown in nutrient solutions containing various combinations of manganese (nil — 400 p.p.m.) and molybdenum (nil — 20 p.p.m.). The appearance of manganese deficiency symptoms was not affected by the quantity of molybdenum provided, and the manganese and molybdenum contents of the leaves were mutually independent of the quantity of each element supplied.

Physiology of nutrient uptake by roots.

The results of work by Dr. E. C. Humphries on nutrient uptake by excised root systems of barley and peas, summarized in previous Annual Reports, have now been published (27, 28) and discussed in the light of current theories of ion absorption. The roots were taken from plants grown in solution culture with a range of conditions of nutrient supply, and nutrient absorption was measured in a subsequent period when the root systems were held in constant

conditions in the laboratory. It was shown that the rate of uptake of a particular element depends on the concentration of that element already present in the root, and on the total carbohydrate content of the root, but appears to be independent of the concentration of other elements. It is concluded that the results are best explained on the assumption that absorbed ions combine with special substances in the root cells. Sugar is probably a precursor of these ion-binding substances.

Subsequent experiments have confirmed the importance of carbohydrate supply by showing that addition of sucrose to the nutrient solution in which the excised root systems are held increases the rate of uptake of nitrate, phosphate and potassium.

Investigations have also been started on the absorption of ions by roots of intact plants. By a special device for sealing intact roots into a vessel containing culture solution, it has been possible to follow ion-uptake and respiration by the root simultaneously. One of the objects of these experiments is to see if there is an increase in respiration rate when active ion absorption is occurring; this should be so, according to the "salt respiration" theory of ion absorption, but has not been confirmed in experiments with excised roots. An interesting fact which has emerged from these experiments is that, in spite of maintaining the intact roots at a constant temperature, the respiration rate exhibited a diurnal rhythm, and was higher during the day than at night. This is probably connected with variation in the carbohydrate supply from the shoot, but so far this point has not been specifically investigated.

The installation of a compressed-air supply in the glasshouses has enabled experiments on the effect of aeration on the growth and uptake of ions by barley plants to be begun. The analytical results of these experiments are not yet complete.

Uptake of nutrients from solutions sprayed on leaves

Miss G. N. Thorne has completed the chemical analyses of plant material from her 1950 pot experiments. In one of these, the leaves of sugar beet plants were sprayed daily with a nutrient solution supplying nitrogen, phosphorus and potassium either for eight weeks in the early part of the growth period, or for the subsequent nine weeks. Early spraying caused a greater increase in final dry weight and in total nutrient uptake than late spraying, but did not appreciably affect nutrient content per cent of dry matter, while later spraying increased the per cent content of N and P.

It was noted in the 1950 Report that spraying with a nutrient solution had no effect on the growth or yield of tomato plants, although these were grown in poor soil and showed symptoms of nitrogen and potassium deficiencies. Chemical analyses have now established that the nitrogen and potassium contents of the plants were increased by spraying. The reason why tomato plants, unlike other species tested, failed to show growth responses to nutrients taken up through the leaves is not known.

In all the 1950 experiments the spray solution supplied nitrogen, phosphorus and potassium together. To find out whether the presence of one nutrient in a solution sprayed on the leaves affects the uptake of other nutrients, either from the spray solution or

through the roots, an experiment was made on sugar beet in 1951 in which nitrogen, phosphorus and potassium were applied in spray solutions separately and in factorial combination. Harvests were made after spraying daily for 4, 8 and 11 weeks. Nitrogen caused a marked increase in leaf area and in the dry weights of all parts of the plants at all harvests, and at the last harvest potassium also increased dry weight.

A second experiment was done to compare the uptake of Na, K, Ca and Mg from solutions containing equivalent concentrations of the chlorides. None of the spray treatments gave increased yields, presumably because the soil supplied adequate amounts of these elements.

A third experiment compared uptake of nitrogen from solutions of ammonium sulphate, calcium nitrate and urea of equivalent nitrogen content. Sugar beet plants sprayed with these solutions had darker green leaves than plants sprayed with water, and the leaf weight was also increased. Calcium nitrate and urea increased root weight, but ammonium sulphate had a much smaller effect, possibly because it caused some scorching of the leaves in the later part of the experimental period. The total nitrogen uptake was nearly identical for all three nitrogen compounds.

It is not known whether uptake of nutrients from the spray solutions is limited to the period when the leaves are still wet, or whether it can take place from the dry deposit of solute after the solutions have evaporated. If the former is true, increasing the length of the wet period by spraying with water should increase nutrient uptake. This was tested in an experiment where plants were sprayed with nutrient solution on two days each week, half of them receiving additional sprayings with water on the other days.

An experiment planned in 1950 to measure the effect of nutrient sprays on the growth of barley failed through mildew infection, and was repeated in 1951 on a mildew-resistant variety. Spraying with a complete nutrient solution increased the number of tillers, and the yield of grain and straw. When the plants were ripening, the foliage of the sprayed plants remained green longer than that of the unsprayed.

Much of the information on nutrient uptake that these experiments will give is not yet available, because the chemical analyses are incomplete. Measurements of leaf area made at regular intervals will enable the efficiency of absorption per unit leaf area of different substances and at different periods of growth to be compared.

The glasshouse experiments so far described were intended to establish the possibility of nutrient uptake through leaves and measure its extent and its effects on growth, and frequent sprayings were used to ensure maximal effects. Such frequent sprayings over long periods of time would obviously be impracticable in the field. It is possible, however, that useful results may be produced in field crops by a few sprayings at an appropriate stage of growth. As the quantities of nutrients taken up depend on leaf area, such sprayings are likely to be effective only at times when the crop has developed a large leaf area. One possible application of this method of nutrient supply is to increase the nutritional value, particularly the protein content, of green forage crops. In collaboration with the Biochemis-

try Department, a field experiment was made to test whether the protein content of sugar beet leaves can be increased by spraying with a solution of a nitrogenous fertilizer at a stage close to harvest, without serious adverse effects on the sugar content of the roots. If successful, this might provide a valuable method for rapidly converting inorganic nitrogen into protein. Apart from increasing the feeding value of the beet tops, it would improve their value as material for extraction of leaf protein by the methods developed in the Biochemistry Department.

Field plots of sugar beet were sprayed with a 3 per cent solution of ammonium nitrate on six occasions in two periods of three weeks at the end of August and in September; the total amount of ammonium nitrate so applied was 180 lb. per acre. At harvest in mid-October, spraying had increased the dry weight of leaf lamina by 20 per cent. The nitrogen and protein contents per cent of dry matter were both raised, and the yield of protein in the leaf lamina was increased by 30-50 per cent depending on the time of spraying. The total recovery of nitrogen in the whole plant was 80 per cent of that applied in the spray solution. The nitrogen content of the roots was increased by some 16 per cent, but data on the effects on sugar content are not yet available.

Work has been started to develop a method of measuring nutrient uptake by leaves over short periods of time by the use of radioisotopes.

Potassium deficiency in sugar beet

Previous work has shown that sugar beet are not very sensitive to variation in potassium supply, provided the level of sodium supply is kept high, suggesting that sodium can fulfil some of the functions of potassium in the plant. However, when potassium salts were omitted from nutrient solutions used in sand culture so that the only potassium available was that present in the seed or as impurities in the other salts or in the sand or water, and ample sodium salts were given, growth, especially of the storage root, was greatly reduced though the plants survived for long periods. In these conditions the rate of carbon assimilation was very low, and the plants were very depleted in carbohydrate. It therefore seemed possible that the effect of lack of K on growth in these conditions might be due to carbohydrate deficiency resulting from impairment of the photosynthetic mechanism.

To test this, sugar beet plants grown in sand culture with addition of sodium but no potassium salts were sprayed daily with a 10 per cent solution of sucrose. Though the sugar content of the leaves was increased by spraying, indicating that sucrose was absorbed, there was no appreciable effect on growth. It appears, therefore, that the effect of potassium deficiency on carbohydrate production by photosynthesis does not account for the decreased growth of the plant, but that some other part of the growth process must also be affected.

Effect of Water Potential on Germination and Water Uptake of Wheat Seeds

The results of Dr. P. C. Owen's work on this problem have now

been prepared for publication (29, 30). As the work has now been discontinued it is appropriate to summarize the conclusions, although some of them have already been given in previous Reports.

Germination

The critical level of water potential necessary to inhibit germination of wheat seeds completely is much lower than was expected. After 15 days, 20 per cent of the seeds germinated at a potential of −320 metres of water or a pF of 4·5, well below Permanent Wilting Point which is generally accepted to be at pF 4·2, or a potential of −160 metres of water. Under very extreme conditions, air drying can produce a soil pF of 6, equivalent to a relative humidity of 50 per cent, but this would not normally occur in the field in a temperate climate except at the surface of the soil. Recent Danish work has shown that the relative humidity in the soil rarely falls as low as 98 per cent, therefore the moisture conditions corresponding to a pF of 4·5 or a R.H. of 97·7 per cent can be considered as extremely dry.

In the soil moisture conditions of any normal seed-bed there appears to be no reason connected with water supply why emergence of the radicle from the seed should not occur eventually, but this does not imply that subsequent growth will always be satisfactory. Low potentials delay germination, and there is evidence that they reduce the viability of the seeds by increasing their susceptibility to fungal and bacterial infection. It follows that failures of crop establishment in the field during drought periods are probably not attributable to inhibition of germination, but may be the result of subsequent failure of the young seedlings to withstand low water potentials or of a high death rate of seedlings due to attack by pathogenic organisms.

Water uptake

At water potentials near to −250 metres of water (R.H. 98 per cent) the uptake of water by wheat seeds from air dryness to equilibrium moisture content can be satisfactorily represented by a curve of form :—

$$y = y' (1 - e^{-at})$$

where y = water content at time t and y′ = equilibrium water content. If the initial water content of the seed is y° this becomes :—

$$y' - y = (y' - y^\circ)\, e^{-at} \quad \ldots \quad \ldots \quad 1$$

After the onset of active growth of the embryo, the subsequent increases in water content over the short times studied may be expressed by :—

$$y - y' = (y' - y^\circ)\, e^{bt} \quad \ldots \quad \ldots \quad 2$$

At these low water potentials, curves of the form given by equation 1 fitted to the data for living and for dead seeds are nearly identical indicating that water uptake in the initial phase is due to physical rather than physiological causes. The second phase of water uptake, represented by equation 2, is presumably due to water absorption by the embryo as its size increases.

The parameter *a* in equation 1 represents, or is directly proportional to, the diffusivity of water in the seed, and would therefore

be expected to be independent of water potential. However, as noted in the 1950 Report, curves fitted to the data obtained from seeds held at different water potentials gives values of a that decrease with increase in potential from —250 metres to zero.

Consideration of the results for dead seeds or, more strictly, seeds the germination of which was inhibited by exposure to propylene oxide vapour, suggests that for water potentials near to zero, the simple exponential relation given by equation 1 is inadequate to represent the initial physical phase of water uptake, because the water content did not approach a constant value within the experimental period but continued to increase. It is therefore postulated that for water potentials near to zero, the curve of water content is the sum of two components, (1) a curve of the form given by equation 1, and (2) a curve showing exponential approach to a constant rate of uptake. The water content y and time t can then be expressed by the equation :—

$$y - y^{\circ} = \frac{A - B}{a}(1 - e^{-at}) + Bt \quad \ldots \quad \ldots \quad 3$$

where A = initial rate of uptake when t = 0, B = constant rate of uptake reached when t is large, and a has the same significance as before. Curves constructed on this hypothesis fit the observed values satisfactorily when the same value for the diffusivity a is used over the whole range of water potential tested, and the anomalous variation of a with water potential disappears.

It is suggested that the component (2) of the total uptake curve is attributable to some change within the seed that is initiated at water potentials near to zero, but not at low potentials near to —250 metres, within the duration of the experiments. This change may be the production of sugar by starch hydrolysis, and its failure to develop at low potentials may partly account for the retarded germination observed at low potentials.

Biology of Wild Oats

Miss J. M. Thurston's work on wild oats has dealt with the following problems :—

Germination and dormancy

It was previously noted (1950 Report, p. 58) that a higher proportion of wild oats seeds germinated in the first season when they were sown in farmyard manure than in soil. In the second season, this result was reversed ; many fewer seeds germinated in farmyard manure than in soil. Thus, farmyard manure not only tended to break the dormancy of the seeds in the first season, but it also greatly reduced germination in the subsequent season, and the total viability of the seeds. Both these effects may have practical value.

To find out whether viable seeds can be spread in animal excreta, a calf, bedded on peat in a loose-box, was fed 2,000 seeds of *A. ludoviciana* mixed with its food. The manure and peat were collected, spread in trays, and kept moist in a glasshouse. In the first 11 months only seven wild oat seedlings have appeared. This suggests that the risk of spreading wild oats by farmyard manure

applications is small. The material is being kept, as viable but dormant seeds may still remain in it.

In the field experiment started in October, 1950, to give information on seasonal germination and the period of survival of wild oats seeds in the soil, germination in the first season was low, ranging from 3 per cent to 15 per cent for different treatments. There was a differential response of the two species to depth of sowing; more seeds of *A. fatua* germinated when harrowed in on the surface than when buried 6 in. deep, but for *A. ludoviciana* this result was reversed and the deeper-sown seeds showed the greater germination.

Attempts to work out the temperature relations of germination have been hampered by lack of equipment for providing controlled temperatures within the appropriate range. A series of germination tests of whole spikelets of *A. ludoviciana* was made at fluctuating or fairly constant temperatures between 30°F and 90°F. First and second seeds germinated most readily at steady temperatures between 45°F and 55°F and more slowly at temperatures varying between 50-70°F or 30-70°F. All the first seeds of the spikelets germinated at these temperatures but only about 50 per cent of the second seeds germinated at 45-55°F and about 10 per cent at 50-70°F and 30-70°F. At just above freezing point, 95 per cent of the first seeds, but none of the second seeds, germinated between three and four months from sowing. No seeds germinated at constant temperatures of 30°F, 68°F, 85°F or 90°F or at temperatures fluctuating between 50°F and 90°F. After two months all seeds held at 90°F were dead, but nearly 100 per cent of first seeds held at the other temperatures germinated in three weeks when transferred to the more favourable temperature range of 45-55°F.

Diagnostic value of seed characters

Wild oats seeds received from various parts of England in 1950 (1950 Report, p. 58) varied considerably in appearance and some differed from those occurring at Rothamsted. Twenty-two selections of *A. fatua* and seven of *A. ludoviciana* were therefore sown in pots in spring, so that the plants grown from them in similar conditions could be compared at all stages of development.

In general, plants of *A. fatua* bore seeds similar in husk-colour and hairiness to those from which they were grown. Differences in plant characters were small, and were not closely correlated with seed characters. This throws doubt on the validity of sub-dividing the species *A. fatua* into a number of varieties based only on seed characters.

No morphological difference in the growing plants was found that could be used to distinguish between plants of *A. fatua* and the normal brown-husked type of *A. ludoviciana* before the flowering stage. However, three grey-husked selections of *A. ludoviciana* type differed from all the others in a number of respects, and could easily be picked out from among the randomized pots of the experiment at all stages. They had narrower and more drooping leaves and a greater number of shoots, and the ears emerged later. The later flowering and ripening of this grey-husked type may have some agricultural importance, but the normal season of germination of these seeds in the field is not known, and if it is autumn or winter

the ears may be produced at about the same time as those of later germinating but quicker ripening sorts. However, the late date of collection of two of these selections suggests that in field conditions they ripen later than other wild oats.

Distribution of A. fatua *and* A. ludoviciana *in England and Wales*

A survey of the distribution of wild oats, covering almost the whole of England and Wales, was made possible by the co-operation of the National Agricultural Advisory Service. Officers of the National Agricultural Advisory Service collected nearly 600 samples and a few were received from other observers.

Almost all samples contained *A. fatua*. The range of this species covers all parts of England where wheat and barley are grown, from Berwick in the north, all down the east side between the Pennines and the coast, all the Midlands as far as the eastern borders of Staffordshire, Derbyshire and Shropshire, and all southern England east of Exeter. Wales was reported free of wild oats except for a small area of *A. fatua* in Monmouthshire.

A. ludoviciana has a much more restricted range. It occurred in about 70 samples from an area roughly within 80 miles radius of Oxford, reaching from Somerset in the west to Essex in the east, and from Warwickshire in the north to the Isle of Wight. The highest concentrations of samples were between Faringdon and Oxford, between Leamington and Rugby and on the plain west of the Chilterns from Bedford to Aylesbury.

Information on the soil type, on the density of the infestation and on the agricultural history of the land was supplied with each sample, but this has not yet been analysed.

Physiological Effects of Virus Infection

In co-operation with the Plant Pathology Department, a pot culture experiment on broccoli was made to investigate the effect of nutrient supply on the symptoms caused by infection with broccoli mosaic and cabbage black ringspot viruses. The results are not yet analysed. It was also intended to measure the effects of infection on growth and yield, but natural spread of infection from outside sources interfered with this.

STATISTICS DEPARTMENT

By F. Yates

As in previous years the work of the department falls into two main sections—(1) design and analysis of experiments; (2) sample surveys and operational research.

Design and Analysis of Experiments

The department has continued to design and analyse field and laboratory experiments for Rothamsted and other research stations. A great deal of work on these lines is also carried out for the National Agricultural Advisory Service. Dr. Boyd and Dr. Cooke of the Chemistry Department have held two courses of lectures for the National Agricultural Advisory Service on field experimentation, and a member of the department usually attends meetings of the Provincial Experiments Committees. A note by Dr. Boyd and Mr. Dyke on "The Place of Statistics in Field Experiments" has been circulated within the National Agricultural Advisory Service (51). Dr. Yates is a member of the Crop Experiments and Animal Experiments Sub-Committees of the Agricultural Improvement Council's Experimental Husbandry Committee and of a number of their working parties. On the animal side he has been assisted by Mr. Rees, who, with Mr. Westmacott, forms a small unit which has been specifically set up to deal with problems in the design and analysis of animal experiments.

The amount of computing work carried out in the department is now very considerable. A comparison with 1934 is made in the following table :—

	No. of experiments			*Plot yields analysed*		
	Rothamsted, Woburn and outside centres	N.A.A.S.	Total	Rothamsted, Woburn and outside centres	N.A.A.S.	Total
1934	115	—	115	9,142	—	9,142
1951	288	149	437	32,496	25,452	57,948

During this period the output of a computer has risen from about 2,500 plots to about 7,500 plots per annum. Part of this increase is due to some simplification of the processes of analysis, but it can largely be attributed to the improved types of calculating machines now in use, and to the careful organization of the work by the computers themselves. In considering these figures, it should be noted that almost all analyses are now carried out in duplicate by different computers and subsequently compared to detect arithmetical errors.

On the theoretical side, Mr. Healy has summarized the useful designs for 2^n factorial experiments using 32 plots (39). Mr. Patterson has continued his investigation of experiments involving sequences of treatments and has published a further paper on this subject (41). These designs may be used for agricultural rotation experiments and for experiments on animals. He has also worked out the principles of analysis for the Rothamsted 3- and 4-course rotation experiments. The analysis of the 18 years' data from the

3-course experiment has been completed, and various modifications have now been introduced into the design of the experiment which it is hoped will throw light on the causes of the differences already produced by the treatments. A discussion of the experiment is given elsewhere in this Report (p. 135).

Dr. Yates has made some progress on his projected book on experimental design. The possible designs of the $2^p \times 4^q$ type have been explored, using confounding and fractional replication where necessary. A scheme for including a fourth factor at three levels in a series of 3^3 experiments in 27 plots has been developed. A design for plant selection work in coffee in which 100 or so progenies, each of about 20 plants, are to be tested was worked out and a paper on this was read and discussed at a meeting of the Biometric Society (43). A discussion of the analyses of a poorly-designed long term rotation experiment is to be published in the Brazilian journal *Bragantia* (42).

Sample Surveys and Operational Research

The Survey of Fertilizer Practice was continued during the year in 11 counties. The statistical analysis has been under the supervision of Mr. Church. A general report on the 1950 results has been issued (53) together with a report on the results from Cardiganshire in 1945 and 1950 (60). Mr. Church is also investigating sampling errors and biases in this survey and some interesting results have already emerged. A general discussion of the survey by Dr. Yates and Dr. Boyd was given in a paper before the Edinburgh meeting of the British Association (46).

The main field work in the Survey of Maincrop Potatoes came to an end last year, but further field sampling was carried out in 1951 to investigate yield forecasting. A report on the results from the Northern province has been written (50), and the final analysis of the complete results is nearly ready. Some results relating to the yields estimated by field sampling and the official Ministry of Agriculture estimates are set out below. The official estimates have been well below the sample figures in all three years. Detailed examination shows that this is due mainly to under-estimation of high yields.

Yields of potatoes (1¼ in. ware) in tons per acre

	1948	1949	1950
Official estimates (excluding first earlies—sampled counties only)	7·8	6·8	7·8
Sample estimates	9·5	8·5	9·9
Excess of samples	+1·7	+1·7	+2·1

The sample estimates were checked by comparison with the farmers' weighed yields where these were available. There was excellent agreement in 1948 and 1949, but some discrepancy in 1950. Part at least of this discrepancy is believed to be due to losses during storage, since some of the farmers' weighings were carried out in November or December, and 1950 was a bad blight year.

Yields of potatoes (1¼ in. ware) in tons per acre

	1948	1949	1950
Farmers' weighed yields	9·8	7·8	9·1
Sample yields on same fields	9·9	7·6	10·0
Excess of sample estimates	+0·1	−0·2	+0·9

Samples were taken in August, 1949, 1950 and 1951 to investigate the possibility of a system of crop forecasting. While further work is necessary before any definite conclusions as to the value of the method can be reached, the results so far attained suggest that reasonably satisfactory forecasts may be possible. The results are included in a general discussion of crop forecasting given by Dr. Yates at the Indian meeting of the International Statistical Institute (45).

The survey of Restored Opencast Coal Sites mentioned in last year's Report was carried out during 1951. Field work is not yet completed, but analysis is going ahead on the data so far available, and a preliminary report will soon be issued. The department is also assisting the National Institute of Agricultural Engineering in an operational survey of farm tractors.

Smaller surveys included a survey of brassica crops grown for stock feeding in Wales (54) and a survey of rabbit damage to winter wheat carried out by the Advisory Entomologists. Mrs. Lord and Mr. Lessells analysed a survey of ragwort infestation in Anglesey and Pembroke (55). Two main factors effective in controlling this weed were found to be grazing by sheep and mowing for hay. Ploughing and reseeding may cause a temporary improvement, but ragwort infestation builds up again in two or three years if management favours its spread.

Dr. Boyd has written a paper with Professor Ellison of the Department of Agriculture, University College of Wales, based on the results of the Survey of Marginal Land carried out in 1949 and 1950 (37). It is estimated that there is about 2·4 million acres of marginal land under private occupation. Leaving aside the acreage regarded as not worth improving, the present output per acre of this land could be increased by about 70 per cent by a capital investment of about £40-45 per acre; rather less than half this sum would be needed for improvements to the land itself, and most of the remainder for the construction of additional buildings, roads and services. As a result of his work on this survey Dr. Boyd was asked to become a member of a working party of the Cabinet Natural Resources (Technical) Committee, dealing with the relations between agriculture and forestry.

At the request of the United Nations Statistical Office, Dr. Yates attended a meeting of the Working Party of Experts on Statistical Information of the Inland Transport Committee, Economic Commission for Europe. As a result of this meeting he prepared two notes on sampling road vehicles (61, 62).

Colonial work

Mr. Hodnett has continued to deal with a number of enquiries from Colonial research workers. These have included discussions of agricultural, economic and population surveys and requests for

advice on the design and analysis of a wide variety of experiments. He has continued his study of published data on the fertilizer responses of sugar cane. Mr. Church has supervised the analysis of a large uniformity trial carried out at the Oil Palm Research Station, Nigeria, and Mr. Hodnett is analysing a similar trial on groundnuts from Tanganyika. These two analyses, which are being carried out on Hollerith equipment, should enable the workers concerned to choose the best size and shape of plot for their experiments. As usual, many Colonial workers have visited the department during the year, three of them for prolonged periods.

Dr. Yates visited Jamaica during January, where he led a seminar on sampling methods organized by the Institute of Social and Economic Research of the University College of the West Indies. He also paid a brief visit to the Imperial College of Tropical Agriculture, Trinidad.

Other Work

Dr. Boyd has written two notes summarizing published data on the effect of seed rate on the yield of cereals (34) and on factors affecting the yield of winter beans (52). He has also discussed economic and statistical aspects of vegetable and animal foods in a paper read at a conference of the Nutrition Society (33). This paper deals with the relative physiological efficiencies of the different farm animals and considers how far these measures of efficiency need to be qualified by economic considerations. With Mr. Church and Mr. Dunn, Dr. Boyd has also collated published figures of agricultural production with a view to comparing alternative estimates of the net agricultural output of the country as a whole over the last five years.

Mr. Lessells has written a report for the Agricultural Research Council on the varieties of cereals grown in England and Wales during 1947, using data from the Survey of Fertilizer Practice (57). He has also summarized published data on the effect of seed size and spacing distance on the yield of potatoes and is preparing a paper on the subject with Dr. Boyd.

A paper was completed by Mr. Dyke and Mrs Simpson on the results of a large collaborative experiment on methods of analysis of pyrethrum (36). On rather similar lines, Dr. Boyd and Mrs. Simpson prepared a report on the sources of error affecting determination of the lime, phosphate and potash status of a field based on data collected by the Advisory Soil Chemists over a period of years (59). For a sub-committee of the Analysts' Conference of the National Agricultural Advisory Service, Mr. Lessells has reported the results of an investigation into the comparability of the analytical methods in use at provincial centres (58).

Dr. Grundy has continued his work on the log-normal distribution encountered in the sampling of insect populations and a paper has been published (38). He also assisted the Physics Department in the numerical solution of differential equations. Mr. Dyke and Mr. Patterson have written up their method of analysing factorial experiments when the results take the form of proportions (35). Mr. Healy has continued to advise on the analysis of the data furnished by the Birmingham Anthropometric Survey, and a paper

on the general problems encountered in the analysis is nearing completion. Dr. Yates and Mr. Healy contributed to a correspondence in *Nature* concerned with methods of handling multiple measurements on the teeth of human beings and the great apes in relation to similar measurements on the anthropoid fossils recently discovered in South Africa (47). Some interesting general problems of multivariate analysis are involved, and further work on this topic is in progress. Mr. Healy has also published a table of the correction for natural mortality used in assays of insecticides, fungicides, etc. (40).

A new edition of " Statistical Tables for Biological, Agricultural and Medical Research Workers " has been prepared and is awaiting publication. Work on a new edition of " Sampling Methods for Censuses and Surveys " is in progress.

Hollerith equipment

The installation has continued to be used in a wide variety of problems. Its usefulness has been increased by the acquisition in March of a reproducer-summary punch. This machine enables rapid copying from one card to another, and also enables the results of calculations done on the Tabulator to be punched direct on to cards.

A variety of non-standard techniques have been devised to meet problems of statistical computing. Many of these involve the use of the modifications to the tabulator mentioned in last year's report. Mr. Avis has standardized a method for analysing a series of 3^8 factorial experiments and Mr. Dyke and Mr. Healy have worked out a method for solving the large systems of simultaneous equations that arise in the critical study of survey data.

Staff

As mentioned above, Dr. Yates visited Jamaica and Trinidad in January and February. In March he visited Sweden under British Council auspices and gave lectures on modern statistical techniques in Stockholm, Lund, Ultuna and Uppsala. Dr. Yates spent July and August at the Instituto Agronomico, Campinas, Brazil, where he co-operated with members of the Statistics Division in a general review of the experimental methods used at the Research Station. He also visited a number of the regional stations attached to the Institute. He gave a series of lectures at the Institute, and a lecture on sampling methods to the Instituto Brasileiro de Geografia e Estatistica in Rio de Janeiro (44).

Dr. Yates also attended the fifth meeting of the United Nations Sub-Commission on Statistical Sampling held in Calcutta in December. Before this he attended meetings of the International Statistical Institute and the Biometric Society in New Delhi and Calcutta. While in India Dr. Yates also visited the Silvicultural Research Station at Dehra Dun and the Central Rice Station at Cuttack.

Mr. Healy spent five months in France under a scholarship from the Institut Nationale de la Recherche Agronomique. Most of the period was spent at the Station Centrale de la Zoologie Agricole at Versailles, but Mr. Healy also visited other research stations including the Institut des Tabacs at Bergerac. Towards the end of his

stay he gave a short course of lectures on statistical techniques in biology (56). During August, Dr. Grundy and Mr. Church attended a course in genetics at the John Innes Horticultural Institution.

Mrs. R. Lord resigned from the department at the end of the year, and Mr. Jolly left in May 1951 to take up an appointment at East Malling as statistician to the National Agricultural Advisory Service Horticultural Experiment Stations, specializing in experiments on fruit. Two new appointments to the scientific staff were made during the year; Miss E. Spetch from University College, London, and Mr. M. H. Westmacott from Corpus Christi College, Oxford.

TEMPORARY WORKERS 1951

Great Britain		
J. K. W. Slater	National Institute of Agricultural Engineering	November 1950-October 1951
R. W. Shepherd	Norfolk Agricultural Station, Sprowston	May 7th to 18th, 1951
Neil Gilbert	Clare College, Cambridge	June-August 1951
W. B. Taylor	University College, London	July-September 1950, and August-November 1951
Colonial		
M. P. Mulholland	Department of Agriculture, Nigeria	October 1950-January 1951
W. D. Burrowes	Department of Agriculture, Jamaica, British West Indies	June-October 1951
K. Lerche	Sisal Research Station, Thika, Kenya	October-November 1951
I. Watson	Department of Agriculture, Malaya	December 1951-
Foreign		
S. C. Chua	Department of Statistics, Singapore	June-September 1951
Ana Maria Flores	Dirección de Estadistica, Mexico City, Mexico	June-September 1951
M. Ollagnier	Institut des Recherches Pour les Huiles et Oléagineaux, Paris	June-July 1951

PLANT PATHOLOGY DEPARTMENT

By F. C. Bawden

In October T. W. Tinsley was seconded for two years to the West African Cacao Research Institute ; F. M. Roberts' period of secondment to the Clove Research Scheme, Zanzibar, was extended until August 1953.

L. Broadbent and M. A. Watson attended the International Congress of Entomology at Amsterdam in August ; L. Broadbent also attended a conference on potato virus diseases at Wageningen and visited research centres in western Germany, at the invitation of workers there. R. Hull spent August and September in the United States and Canada visiting institutes at which diseases of sugar beet are studied. At the invitation of the Organizing Committee, F. C. Bawden attended the Second International Poliomyelitis Conference at Copenhagen in September. At the request of the Pyrethrum Board, P. H. Gregory visited Kenya in December to advise on the " bud disease " of pyrethrum.

P. H. Gregory was President of the British Mycological Society. T. W. Tinsley was awarded the Ph.D. degree of London University.

Viruses and Virus Diseases

Ultraviolet irradiation

Methods were developed for testing the goodness of fit to various hypotheses of infectivity tests with irradiated preparations of plant viruses, and, with few exceptions, the results agreed with inactivation being a first order reaction. Over a wide range of concentrations, the infectivity of partially inactivated and control preparations behaved similarly when diluted, and there was no evidence that plant viruses give the phenomenon of " multiplicity reactivation," a phenomenon described with bacteriophages of *Bacterium coli* with which particles that are non-infective singly cause infection when two or more enter the same cell. The only differences between dilution curves of irradiated and control preparations were at high virus concentrations, when, instead of the irradiated preparations causing more lesions than would be expected, they caused fewer, evidence that the inactivated particles not only failed to reinforce one another but interfered with the establishment of active ones.

The extent to which irradiation reduced infectivity of tomato bushy stunt and tobacco necrosis viruses depended on whether inoculated leaves were exposed to visible light after inoculation. Preparations that appeared to have their infectivity reduced to 1 per cent by irradiation when inoculated leaves were kept in the dark, had 4-10 times as much residual infectivity when inoculated leaves were exposed to daylight. Illumination of the irradiated virus preparations *in vitro* did not enhance their infectivity ; the effect is not a direct one of light on the virus particles but indirect through some light-sensitive system contained in the host cells. The phenomenon does not apply to tobacco mosaic virus, irradiated preparations of which show the same residual infectivity whether inoculated plants are illuminated or not.

The damaging effect of ultraviolet to plants were also counteracted by visible light. For example, leaves of *Phaseolus vulgaris* irradiated for two minutes showed no macroscopic effects if they were subsequently kept in daylight, but the irradiated epidermis died when leaves were kept in darkness after irradiation (Bawden and Kleczkowski, 78).

Experiments with a *Rhizobium* bacteriophage, gave results in general agreement with those obtained with tomato bushy stunt and tobacco necrosis viruses. That is, there was no "multiplicity reactivation", and more infections were obtained when inoculated cultures of bacteria were illuminated than when they were in the dark. The only difference was that irradiated preparations of the bacteriophage lost infectivity after irradiation more rapidly than did control preparations (Kleczkowski and Kleczkowska).

Inhibitors of infectivity

In collaboration with Dr. G. G. Freeman of Imperial Chemical Industries, the inhibitors of plant viruses present in filtrates of *Trichothecium roseum* were studied. Inhibition is caused by two different substances, both resistant to boiling and drying. One is trichothecin, an anti-fungal substance with a molecular weight of about 300, and the other a macromolecular polysaccharide. Trichothecin is phytotoxic, and its inhibiting effect is greater with *Phaseolus vulgaris*, to which it is also more damaging, than with *Nicotiana glutinosa*. It is equally effective in preventing infection whether present in the inoculum or sprayed over the leaves either before inoculation or up to 24 hours after inoculation. The polysaccharide causes no visible injury to any plant to which it has been applied. Unlike other such inhibitors previously studied, for example, ribonuclease, it does not seem to combine with viruses *in vitro*, but it resembles these in causing inhibition only when present in the inoculum or when applied to leaves before inoculation. The extent to which it inhibits infectivity depends greatly on the species of the host plant on which tests are made and little on the identity of the virus; it much more effectively prevents infection of *N. glutinosa* than of *P. vulgaris*, the reverse of both trichothecin and ribonuclease (Bawden).

Work was also done on the inhibiting action of sap from leaves of sugar beet, cucumber, *Datura stramonium* and *Phytolacca decandra*. Unlike the inhibitors from *T. roseum*, these are heat labile and probably proteins. Again, there is much host specificity in their action, and particularly striking is the fact that they have little effect in preventing infection of the species from which they come (Gendron).

The manner in which these inhibitors act is still obscure. It may be that they combine with the virus particles, and so prevent these from combining with essential receptor substances in the host cells, or that they combine with these receptors. Alternatively, their presence may so alter the metabolism of the host cell that introduced virus particles cannot multiply; this theory readily explains their ineffectiveness in preventing infection of plants that contain them, because a cell would not be expected to respond to something that is normally present.

Environment and susceptibility to infection

Some of the effects of shade and darkness in increasing the susceptibility of plants to infection with viruses have been described in previous reports. This year high temperatures have been found to produce somewhat similar effects. When plants are kept at 36°C for a day or so before inoculation, their susceptibility to infection, as measured by numbers of local lesions, is increased by factors of up to 10. Exposure to 36°C after inoculation has different effects with different viruses. With tobacco mosaic and tomato spotted wilt, effects are comparable to those obtained by putting plants in the dark, the numbers of lesions usually being rather less than those formed by control plants. With tomato bushy stunt, tobacco necrosis and cucumber mosaic viruses, by contrast, there is a great reduction in lesion numbers, and if the high temperature is maintained for a day or more, no lesions develop. Tobacco mosaic and tomato spotted wilt viruses multiply as readily at 36°C as at lower temperatures, whereas the other three appear not to multiply ; the virus content of plants systemically infected with tomato bushy stunt virus fell considerably when plants were kept at 36°C for a week or more, the fall being greater in infective virus than in the total of material serologically related to the virus.

Instead of tobacco mosaic virus being localized in necrotic lesions in *Nicotiana glutinosa* as it is at lower temperatures, at 36°C it causes chlorotic local lesions and a systemic mottle. When infected plants at 36°C are brought to 20°C, all infected tissues rapidly collapse ; as they become necrotic, scopoletin, a substance that fluoresces strongly in ultraviolet light, accumulates (Kassanis).

Variations in water supply also affected the susceptibility of *N. glutinosa* to infection with tobacco mosaic virus. Increasing the water supply increased susceptibility at all times, but did so most in spring and autumn. Differences showed within a fortnight of starting differential watering, and they were reduced by shading plants or by incorporating a diatomaceous earth in the inoculum. Although well-watered plants were more readily infected than others, tobacco mosaic virus reached a higher concentration, in both inoculated and systemically infected tobacco leaves, when plants received less water. Well-watered plants had more succulent leaves, thinner cuticles and a less regularly arranged palisade tissue, than did plants kept dry, and their greater susceptibility to infection possibly reflects the fact that they are damaged more readily and provide more entry points when inoculated (Tinsley).

When the light intensity is low, symptoms of yellows and other diseases in sugar beet plants are indistinct. In attempts to define conditions in which transmission experiments could be made reliably during winter, experiments were started to find the effects of various types of illumination on plant growth and symptoms. The preliminary tests showed that striking responses in growth were obtained in the winter with many different types of lamp, provided these gave 200 or more foot candles at pot level. The general applicability of these tests, however, is uncertain, because the diurnal fluctuations of temperature in the houses were unusual, the temperature being greater at night when the lamps were on than in the middle of the day (Nixon and Watson).

Electron microscopy

Previously we have reported the presence of rod-shaped particles in sap from plants infected with cucumber mosaic virus. Very few were found, but as none had been seen in extracts from uninfected plants, it seemed likely that they were virus particles. Dutch workers, however, have pictured spherical particles with diameters about 75 mμ for this virus. Much work has been done in attempts to resolve these differences, but with little success. Many different plants infected with a range of different strains of cucumber mosaic virus were examined without finding any characteristic particles that could with certainty be identified as virus particles. It seems likely that the rods described previously, although we have still not found them in extracts from healthy plants, are cellulose, and the only particles resembling those described by the Dutch workers seem to be chloroplast fragments.

Similarly, no particles could be identified as virus particles in extracts from plants infected with tomato spotted wilt virus; smear preparations from plants infected with this, and with some other viruses, frequently contain chloroplasts or chloroplast fragments, whereas smears from uninfected plants do not (Bawden and Nixon).

Sugar beet plants with yellows contain characteristic filamentous particles, but the relationship of these with infective particles and with the antigen specific to infected plants still remains obscure (91). The antigen content of infected plants is now several times higher than with the strains current some years ago. Using the specific absorptive capacities of montmorillonite, much material can be removed from sugar beet sap without greatly reducing the precipitin titre with virus antiserum. This has permitted better electron micrographs of the filaments than were previously obtained; it also alters the type of precipitates with antiserum from dense granules, apparently somatic type, to more diffuse floccules, apparently flagellar type (Blencowe and Nixon).

In collaboration with members of the Pedology Department, samples of clays, allophane and synthetic iron oxide were examined (Nixon).

Radioactive isotopes

Various methods were tested for the production of tobacco mosaic virus labelled with P^{32}. The most satisfactory method for obtaining virus with a high activity was to inoculate leaves and then float them on solutions containing radio-active phosphate. More concentrated solutions of the isotope could be used in this method than when plants were grown in water cultures, for high concentrations then caused root damage and prevented normal uptake.

When healthy plants were inoculated with labelled virus, and then later macerated, some of the P^{32} was associated with materials other than the virus. Attempts were made to use the labelled virus to find how diatomaceous earths act in facilitating infection. Virus was inoculated to opposite halves of leaves with and without " Celite ", the leaves washed thoroughly and then assayed for radio-activity. The half leaves rubbed with " Celite " contained only a little more than the others, a difference far too small to account for

the increase in numbers of infections of fifty or more times produced by using " Celite " (Bawden, Kassanis and Nixon).

In collaboration with the Bee Department, P^{32} was also used to find how rapidly and to what extent food introduced by foraging bees was distributed throughout the population of a hive (Nixon).

Sugar beet viruses

Six sugar beet viruses are being studied : (1) Sugar beet yellows virus (S.B.Y.), the strain originally isolated from Rothamsted farm and used in all transmission studies up to now ; (2) S.B.Y., Necrotic strain (N.), isolated from a severely affected field plant in 1948 ; (3) Irish mild yellows (I.M.S.) ; (4) " 41 " yellows, also from Ireland ; (5) Yellow-net virus, isolated from a field plant ; (6) Yellow-net mild strain (Y.N.M.S.), a strain separated from (5). S.B.Y. and N. precipitate with a common antiserum, and plants infected with S.B.Y. cannot be made to produce N. symptoms. None of the other four viruses has precipitated with S.B.Y. antiserum, and none of them protects plants against S.B.Y. or N.

S.B.Y. and N. have been studied in fodder beet and in *Chenopodium foliosum* and *C. capitatum*, which have been stated to be superior hosts for work on purification and serology. Extracts from these plants, however, gave no higher serological titre than from sugar beet infected at the same time, and the two wild species were so stunted that the yield of sap was greatly reduced. The N. strain killed these two species a few weeks after symptoms appeared.

" 41 " yellows virus was seed-transmitted in Kleinwanzleben E. variety of sugar beet. To gain further information on the possible relationships between " 41 " and I.M.S., breeding experiments were started to see whether I.M.S. virus is also seed-transmitted in any variety of sugar beet.

The factors affecting the transmission of Yellow net and Y.N.M.S. viruses by *M. persicae* were studied. Yellow net behaved qualitatively like S.B.Y. virus, but transmission occurred less rapidly. Six aphids per plant were needed to give workable numbers of infections, and a minimum of about 12 hours (six hours infection- and six hours test-feeding) was required for transmission. Y.N.M.S. was more readily transmissible than Yellow net, but it caused less severe symptoms (Watson).

Yellows virus moved out of a sugar beet leaf inoculated by infective aphids within a few hours of the aphids being placed on the leaf. By contrast, several days elapsed before sugar beet mosaic virus moved from leaves inoculated either by aphids or by rubbing with infective sap.

A portable suction trap was devised, suitable for catching representative samples of living winged aphids in the field. The method seems practical, and it was intended to discover what proportion of the alate aphids flying were actually viruliferous, but too few aphids were caught this year.

Experiments on the effects of dates of sowing and singling on crops of sugar beet were done at Dunholme, the Norfolk Agricultural Station, and Rothamsted. Bad weather in the spring delayed sowing, but good stands were obtained, except on the late-singled plots at Rothamsted, where the stand was uneven.

Aphids appeared later than usual, and there were few *Myzus persicae*. *Aphis fabae* were more numerous, but the peak populations of several hundred individuals per plant did not develop until mid-August, and persisted for only a short time. At Rothamsted and Dunholme there were more apterous *A. fabae* per plant on the later sown beet, but alatae were uniformly distributed on the plots sown at different times.

Few plants were infected with yellows virus and none until late in the season. Unlike the previous year, neither sowing date nor time of singling affected incidence. The yields of roots are unlikely to be influenced by yellows, and the harvested yields will give information on the effects of the treatments on healthy crops (Blencowe).

Samples from all steckling beds inspected in the autumn of 1950 were planted in plots at Dunholme. They were very healthy. None showed more than 5 per cent of plants with yellows and most were below 1 per cent. Mosaic and downy mildew were also rare.

Steckling-bed inspections were again organized in the autumn of 1951. The general level of infection with yellows is low and only one bed, which had 7 per cent plants infected, had to be discarded. The mean level of observed plants infected in the beds to be used for planting is 0·07 per cent, only about a quarter of that in 1950.

Stecklings sown in June at elevations of about 1,000 ft. in Scotland developed to a satisfactory size, but those sown in July were small. Small plants did not store satisfactorily ; the larger ones stored well in various forms of clamp, but they did not in sacks kept overwinter in a shed. There were very few infected plants in any of the sowings at the seven centres. Mangolds behaved like sugar beet and grew well after storage, but none of the eight varieties survived the winter out of doors in Perthshire. Red beet, Cheltenham Green Top, failed at all centres.

Several experiments tested different methods of storing sugar beet, mangolds and red beet stecklings during the winter. All the clamping methods were successful, and the only serious failure was from storing bagged plants in a shed. In the warmest storage conditions, the stecklings sprouted and food reserves were lost from the roots (as determined by refractometer, sugar-content or soluble dry matter). A preliminary examination of the results shows a close relationship between the plant establishment and the sugar content of the roots when set out. This may prove helpful in determining whether stored plants are likely to succeed or fail.

In previous years, spraying steckling beds with systemic insecticides has been beneficial in reducing the incidence of yellows. The experiment made in 1950 was valueless, as the control plots had less than 3 per cent infected plants.

Experiments have been made under glass to see how these sprays affect transmission of yellow virus. Aphids were fed for varying periods on unsprayed and Pestox-sprayed plants infected with yellows, and were then transferred to healthy test plants (five aphids per plant). With feeding periods of 10 minutes and one hour, few infections were obtained, but the aphids from sprayed plants transmitted about as frequently as those from unsprayed plants. With feeding periods of 24 hours, however, aphids from the sprayed plants

gave considerably fewer transmissions, and with periods of 48 hours few aphids could be found on the sprayed plants.

Infective aphids (five per plant) were also fed for periods of 2-28 hours on seedlings sprayed the previous afternoon with a mixture of Pestox III and 14, and on corresponding unsprayed plants. All the unsprayed plants except one became infected, whereas only half the sprayed seedlings did. This proportion was the same with all the feeding periods employed. Many aphids on the sprayed plants were dead by the end of the feeding period and others had walked off.

An experiment was arranged to observe the behaviour of aphids put out on sprayed and unsprayed plots and the spread of yellows from infected plants in the centre of the plots. The crop was vigorous, and the plots were singled to compare stands of different density. The aphids put out failed to produce an infestation, and in August and September there were only a very few *Myzus persicae*, which may have developed from migrants arriving in the field. *Aphis fabae* arrived in July and became numerous in August and September, producing many alatae, and they may have spread the virus. Spread from the initial centres of infection was slow, but many isolated infected plants appeared.

Infections were more numerous in plots with a low plant population, which although they contained only half as many plants as the closely spaced plots, contained twice as many infections per unit area. Spraying halved the number of infected plants.

Plots were infected artificially at three different times with a mild and a severe strain of yellows virus. There were pronounced differences in the effects of the virus strains, both on rate of symptom development and on yields (Cornford, Gates and Hull).

Potato viruses

Various manurial treatments in 1950 had no significant effect on the spread of leaf roll virus, but dung significantly increased the spread of potato virus Y. Both viruses spread more in plots planted on March 31st and April 21st than on May 12th and June 2nd.

The results of ten experiments made in 1950 in co-operation with the National Agricultural Advisory Service, eight in potential seed-growing areas of England and Wales, and two in other areas, showed that the time when winged *M. persicae* is active is very important in determining the spread of virus diseases. The ratio, spread of viruses to numbers of trapped aphids, was much greater early in the year than late. Potatoes in seed areas were colonized by aphids later than in the other areas.

In a small preliminary trial, made in 1950 to test the effects of insecticides on the spread of potato viruses, virus Y increased in plots receiving different treatments by the following factors: Control × 31; E. 605 × 19; Toxaphene × 19; Pestox III × 22; Dieldrin × 26; D.D.T. × 37. There was some reduction with all treatments except D.D.T., which apparently irritates aphids and causes them to move more frequently than they would do otherwise. Leaf roll virus spread little in any plot.

The experiments in co-operation with the National Agricultural Advisory Service were repeated in 1951. At Rothamsted, as else-

where, *M. persicae* was late in colonizing the crops, and no large population developed. *Aphis rhamni* was the most numerous aphid on potatoes at Rothamsted. The late appearance of *M. persicae* was remarkable, for other aphids were common. To the end of June 10,000 aphids were caught on 16 traps in different parts of England and Wales, but no *M. persicae* or *Brevicoryne brassicae*. Apparently *M. persicae* failed to overwinter viviparously on outdoor plants.

In 1951 a large experiment was done in co-operation with the Insecticides Department. Plots of potatoes containing a known number of virus-infected plants were sprayed every ten days from emergence to maturity with D.D.T., Parathion, Isopestox, Dieldrin or Toxaphene. The insecticides prevented the development of aphid populations, but their effect on virus spread will not be known until 1952. (Broadbent and Tinsley.)

Viruses of cruciferous plants

Preliminary tests suggested that, in addition to *Myzus persicae* and *Brevicoryne brassicae*, cauliflower mosaic virus could be transmitted by *Acyrthosiphum pisum*, *Aulacorthum sonchi*, *Macrosiphum euphorbiae*, *Aphis fabae*, *Macrosiphum rosae* and *Nasonovia ribisnigri*, and cabbage black ringspot virus by *A. pisum*, *A. fabae* and *M. rosae*. Whether these other species play any part in spreading the viruses in field crops is unknown. As on potato and sugar beet crops, there were fewer aphids than usual on cruciferous crops in 1950 and viruses spread extensively only near allotments or seed plants. Cauliflower mosaic virus was more prevalent than black ringspot ; it also usually causes the more severe disease, but generalizations are difficult because both viruses occur in strains that differ in virulence towards different species and varieties. In general, symptoms caused by cabbage black ringspot virus are prominent only on the lower leaves of infected plants, and growth is not seriously affected, even in cabbage, kale and the cauliflower varieties that react clearly. Cauliflower mosaic virus causes severe diseases in turnip, and most, but not all, cauliflower varieties ; it is moderately severe in kale and mustard, but is tolerated by cabbages and Brussel sprouts. Weekly sprayings of a cauliflower seed-bed with D.D.T., parathion and Isopestox did not significantly reduce the incidence of cauliflower mosaic (Broadbent and Tinsley).

Cauliflower mosaic virus is more stable than cabbage black ringspot, thermal inactivation point 70° compared with 60°, and longevity *in vitro* of six days compared with two. For both viruses, turnip plants were more easily infected than other hosts and provided the best source of virus in insect-transmission work. Both viruses are " non-persistent ", and are transmitted more readily when aphids are starved before they feed on infected plants. Most work has been done on cabbage black ringspot virus, using tobacco as a test plant, because it produces local lesions and gives quantitative results. Preliminary starving for 15 minutes increased transmission, but increases in the period of starving from 1 to 16 hours did not increase it further. When aphids were kept at 4° at the start of the period of fasting, a smaller increase was obtained in the number of transmissions than when they were starved at 17°, or

were first starved at 17° and then at 4° immediately before the infection feeding. Increasing the numbers of aphids per test plant proportionally increases the number of transmissions, showing that individual aphids do not give sub-minimal effects that accumulate to cause infection. Small quantities of infective sap lost infectivity at approximately the same rate at which infective vectors lost infectivity when starved for 6 hours. (Hamlyn.)

Mycology

Spore dispersal

Work has been continued on the dispersal and deposition of spores, both in the open and in the wind tunnel. The deposition in wind-tunnel tests of spores on cylinders of various sizes has been described (86), and attention has been turned to deposition on plane surfaces. This proved unexpectedly complex, and the phenomena encountered await interpretation by aerodynamicists. The results, however, do permit the first reasoned analysis of the spore-trapping methods employed by plant pathologists and allergists. At the commonest wind speeds (below 5 m.p.h.) the horizontal slide as normally used greatly under-estimates the atmospheric concentration of spores, because the edge of the slide modifies the air flow. At high wind speeds (above 10 m.p.h.), spore concentrations are over-estimated, because turbulence increases deposition (Gregory).

One outcome of this work has been the designing, making and testing in the wind tunnel of a greatly improved spore trap (88). This has been successfully used in the field to measure the daily variations in atmospheric spore concentrations. The variations are large and occur in all kinds of weather ; rain reduces the numbers of spores common in dry weather, but leads to the appearance of other types. Over potato crops, sporangia of *Phytophthora infestans* were trapped in quantity only between 08.00 and 18.00 G.M.T., with peak concentrations between 09.00 and 12.00. This suggests that conditions before noon may be an important factor affecting the spread of potato blight, but further work with traps at different heights is needed before definite conclusions can be reached (Hirst).

The atmospheric spore concentrations during 1951 were generally low, for powdery mildews the lowest since trapping started in 1947 ; there were few uredospores, but *Cladosporium* sp. were plentiful and there were heavy showers of smut spores (probably *Ustilago perenanns*) in June (Gregory, Hirst and Last).

Sooty bark of sycamore

Work on this disease, in collaboration with Mr. S. Waller, was continued. The fungus has been described and transferred to a new genus as *Cryptostroma corticale* (87). In addition to observing naturally infected trees, transmission tests were made using spores taken direct from affected trees and mycelium from single-spore cultures. Cut branches to which spore suspensions were applied produced, more often than not, typical stains and sporing lesions within twelve months. A tree inoculated with a pure culture also became typically stained, but it was felled before it spored (Gregory).

Mushroom mummy disease

An outbreak of mummy disease in Yorkshire presented the

opportunity to study this disease, which American workers have suggested may be caused by a virus. Dr. I. F. Storey provided soil and compost from affected beds and, when added to boxes immediately before fruiting, this successfully transmitted the disease. None of our experiments has given results suggesting that it is a virus disease, and some of our results suggest that it is not. Extracts from mummy mushrooms have been added to compost with spawn and with fruiting bodies, and have been inoculated to young " buttons", without reproducing the disease. Pure cultures of the fungus were established on agar media, from pileus tissue and from spores, of both normal and mummy mushrooms. Composts in 8-inch pots were successfully inoculated with these cultures, and with spawn derived from them and grown on wheat grains, but all gave normal mushrooms. Thus the disease appears not to be caused by a virus that is present within the hyphae or spores of affected fruiting bodies. The cause remains undetermined, but seems more likely to be some agent present in the soil that is not perpetuated within the mushroom mycelium (Bawden and Gregory).

Cereal mildews

Powdery mildews were less common than usual, but there was enough on the Broadbalk crop in July to show the importance of manuring in affecting its incidence. The least heavily infected plots were those that were unmanured, or received dung or phosphorus and potash only, and the most heavily infected were those that received 4 and 6 cwt. of ammonium sulphate and 5 cwt. of sodium nitrate in the spring. Fallow also greatly increased the incidence of mildew, the plots on ground fallowed the previous year having a mean number of pustules almost twenty times as great as the others. The effect persists for one year only.

Pot experiments also showed the dependence of infection on the nitrogen status of the host plants and their rate of growth. Plants deficient in nitrogen were highly resistant but became susceptible within ten days of receiving nitrogen. Growth responses to nitrogen were paralleled by increase in numbers of infections, the curve for the second duplicating the first, but with a lag of ten days (Last).

Cereal foot and root rots

A rotation experiment, begun three years ago, was ended, and the whole area cropped with winter wheat. The effects of two years under different crops in freeing land from eyespot, take-all and weeds, which were prevalent in the sixth successive wheat crop in 1948, were tested. Non-susceptible crops were grown in 1949. The 1951 winter-wheat crop followed winter-wheat, barley, oats and spring-sown ryegrass, and 68, 55, 21 and 7 per cent straws had eyespot at harvest; in April, take-all was severe on the roots of 21, 12, 0, 0 per cent plants, and at harvest weeds covered 13, 3, 1, 2 per cent of the plots. Thus, after non-susceptible crops, oats and spring-sown ryegrass eliminated take-all and greatly reduced eyespot. Yields are not yet known, but the beneficial effects of controlling disease and weeds were evident.

In winter-wheat, grown outdoors in pots for the third successive year in the same soil, eyespot reduced mean yield of grain by 44

per cent in unsprayed and by 9 per cent in plants sprayed with H_2SO_4 in spring. Spraying reduced yield of uninfected plants by 13 per cent and increased that of infected ones by 42 per cent. Take-all increased each year and was not affected by spraying. It decreased with increasing applications of ammonium sulphate and increased with increasing seed rate. The extremes were strongly contrasted; in the most thickly sown pots which received no ammonium sulphate, 98 per cent of the plants were severely infected and the roots destroyed; the mean grain yield was 0·8 gm. per pot; in thinly sown pots receiving the heaviest doses of ammonium sulphate, the plants had good roots with no take-all and the mean grain yield was 17·1 gm. per pot. (Glynne and Salt.)

The effect of applying nitrates to winter-wheat at different stages of growth was again studied. Nitrogen applied to uninfected plants at any time before growth had been checked by nitrogen starvation, produced equal increments of grain. Loss in yield caused by eyespot was most reduced by nitrogen applied in March, when it could be most efficiently used by the plant. Thus, equal increments of grain (+ 18·7 gm) were obtained by applying 0·5 gm N. per pot to uninfected plants between November and March, but smaller yields were obtained with April (+12·9) and May (+5·2) applications. Pots without nitrogen yielded only 2·0 gm. By applying 0·1 gm N. at sowing and 0·4 gm later, tillers survived for a longer time and a high yield was obtained with the April (+17·4) and also with the May application (+14·2).

The application of 0·5 gm N. in November, January, March, April and May reduced loss in yield from eyespot from 99 per cent to 25, 34, 18, 39 and 62 per cent, and reduced the percentage of severely infected ear-bearing straws from 100 to 24, 48, 11, 30 and 79, respectively. The application of 0·1 gm N. at sowing and 0·4 gm subsequently, further reduced the loss from eyespot to 22, 25, 11, 28 and 51 per cent for the five dates of application, although the per cent of severely infected straws was not similarly reduced. (Salt.)

On plants grown to maturity in soil in 7-inch pots, two isolates of *Cercosporella herpotrichoides* from wheat, and one from oats, penetrated wheat leaf sheaths more rapidly than barley and caused more severe lesions; they penetrated leaf sheaths of oats and rye more slowly, and caused less severe lesions by harvest. Mean loss in grain yield was 39 per cent in wheat, 22 per cent in barley, and was negligible in oats and rye. These results accord with field observations on relative susceptibility. By contrast, when plants were grown in washed sand, wheat and rye were pentrated more quickly than barley and oats.

An earlier pot experiment showed rye grown in soil to be less susceptible than oats to an isolate from wheat. In Denmark, however, rye seems to be more susceptible than oats. Isolates were therefore obtained from wheat and rye at Lyngby, and compared with those from wheat and oats in England. Both in soil and sand, the isolate from rye penetrated more slowly into wheat and barley and much more quickly into rye than the other three isolates. Differences between susceptibility of oats and rye in England and

in Denmark, therefore, may reflect differences in the strains of the fungus prevalent in the two countries.

When plants grown in sand were inoculated with *Corticium* (*Rhizoctonia*) *solani* the fungus attacked wild oats (*A. fatua* and *A. ludoviciana*), and killed many seedlings of rye and oats; it attacked wheat and barley much less severely (Glynne).

Potato blight

Work was started on the survival of *Phytophthora infestans* in potato tubers. Naturally infected King Edward tubers from a 1950 field crop were stored in boxes, and planted under glass in the spring of 1951. Out of twelve plants that produced shoots in March, six developed blight lesions on one or more shoots. No lesions appeared after mid-April on these plants, probably because the high temperature in the glasshouse killed the fungus.

The effects of climate on potato blight, and the value of warning systems based on temperature and humidity data, were tested by taking continuous readings with wet and dry bulb thermographs kept in (1) a Stevenson screen at 4 feet above ground, (2) level with the tops of ridges on bare ground and (3) in potato crops. The conditions of a " Beaumont period", 48 hours with temperature not falling below 50°F and relative humidity above 75 per cent, were needed for blight to occur; these conditions sometimes happened within the crop but not in the screen, and the screen records were, therefore, less reliable in forecasting outbreaks.

Small plots of the potato varieties Canso and Keswick, bred in Canada for resistance to blight, were grown; both varieties developed blight about a month after its appearance on surrounding plants of the variety Majestic. Dr. M. A. Keay of the Potato Genetic Station, Cambridge, had previously tested the varieties and found them resistant to strains A and C, but not B, and she identified the strain attacking them in the field as one of the B forms. (Hirst.)

Clubroot of cruciferous plants

The factors affecting the survival of *Plasmodiophora brassicae* in the soil and the production of clubroot (90) were further studied. Contrary to previous results, varying the time at which nutrients were applied did not affect the numbers of clubs produced, but, as before, increased manuring increased them. The effect is probably a simple reflection of the increased growth of the plants produced by heavier manuring.

Increased attention was given to techniques for studying spore germination and infection in laboratory conditions. Methods are still being developed and cannot yet be regarded as satisfactory, but some progress was made. Many root-hair infections were obtained by growing cabbage seedlings in small horizontal tubes containing spores in a dilute solution of mineral nutrients. Seedlings infected in this way were transferred to larger water-culture vessels and some produced clubbed roots. The chief difficulty in getting this result is to grow the cabbage plants so that the infected epidermal cells do not die before clubbing occurs.

Spores removed from the small tubes in such experiments were examined and sometimes many empty (germinated) spores were

seen. Standing drops of spore suspension were more convenient for quantitative observations on germination, because counts can be made on the spores *in situ*. Germination has sometimes occurred readily under these conditions, but results were highly erratic, for unknown reasons. Germinating spores were seen, and the zoospores emerged through small pores in the spore wall. (Macfarlane.)

Sugar-beet downy mildew.

Work was continued on the factors affecting the incidence and spread of sugar-beet downy mildew. Many affected plants are killed by frost, and the disease is most prevalent after mild winters and when the monthly rainfall from June to September is between 1·5 and 3·5 inches. Isolation from seed-crops and other overwintering sources of the fungus is the simplest control measure and serious outbreaks are rare at distances of more than half a mile from such sources.

Seedlings are readily infected and plants become increasingly resistant as they age. In dry air spores remain viable for periods up to two weeks. In damp air, some germinate within a few hours, others take several days ; the proportion that germinates, and the time at which they do so, varies widely with different batches. In damp air, the spores remain attached to the coniophores, but in dry air they are readily detached. (Cornford.)

BIOCHEMISTRY DEPARTMENT

By N. W. Pirie

Nucleoproteins from Normal and Virus infected Leaves

(M. Holden and N. W. Pirie)

Factors influencing the infectivity of a tobacco-necrosis virus are being studied with particular attention to the conditions under which there are losses of activity during a few days' storage at 4°. Preparations have approximately the same initial infectivities whether they are made by ultracentrifuging leaf sap once or twice either directly or after dilution. When compared again after an interval of 1-4 days twice centrifuged preparations retain their infectivity substantially unaltered but the infectivity of those centrifuged only once falls, especially if the sap is diluted before centrifuging. This fall can be prevented by the addition of azide. Thus far the phenomena are invariably reproducible so long as leaves in a more or less standard physiological state are used. Many preliminary treatments of the sap, e.g. short periods of ageing before the first ultracentrifugation, dialysis, freezing, shaking with chloroform have given preparations that after only one ultracentrifugation, retain their infectivity. The precise nature of this phenomenon is still obscure, but work proceeds on the hypothesis that the inactivation is due to an unstable enzyme system associated with the sedimentable normal nucleoprotein of the leaf, acting on residual unsedimentable substrate(s) in preparations that have only been centrifuged out once. The system is of interest because the unrecognized occurrence of this type of inactivation can vitiate studies of the relative infectivities of virus preparations made from plants that have been treated differently and also because, if any similar processes go on in the leaf they must influence the course of a virus infection. (In collaboration with F. C. Bawden.)

The state of combination of phosphorus in the normal tobacco leaf continues to interest us and four fractions have been separated : (1) P soluble in cold dilute acid, (2) lipid P, (3) ribonucleic acid P, (4) deoxyribonucleic acid P. The distribution of P in the four fractions was determined in fibre, chloroplast suspensions and precipitates from sap.

The P soluble in cold dilute acid is inorganic phosphate and organic compounds of low molecular weight. Most of the lipid P is not extractable with ethanol-ether until after the tissue has been extracted with acid. Ribonucleic acid (RNA) can be extracted in the form of nucleotides by soaking leaf tissue in dilute perchloric acid at 16° overnight. Deoxyribonucleic acid is not soluble under these conditions, but is brought into solution when the tissue is incubated in perchloric acid at 37° overnight. The separation of RNA and DNA is not perfect, but the RNA fraction is substantially free from DNA though the DNA fraction contains some RNA.

Colorimetric methods, which have been used for determining DNA in animal tissues, have been investigated for their applicability to plant material, In these methods the interference caused by substances such as pectin and its breakdown products, which

are likely to be present in most plant extracts, has been studied. All the methods have some disadvantages, but when DNA-containing extracts can be prepared that are free from RNA it should be possible to get good agreement between values for DNA determined colorimetrically and by P estimation.

The different forms of P in the leaves of several other species of plants, and in tobacco leaves of different ages have been compared. The differences between various species are no greater than between leaves of different ages in the same species. Small young leaves have a high P content and during expansion although the total amount of P present increases, when it is expressed on a dry matter basis there is a marked fall. Nucleic acids form a greater proportion of the total P in young leaves than in old, which have a higher lipid P content. The amount of deoxyribonucleic acid P per leaf remains constant during expansion. Of the total P in the tobacco leaf about 30 per cent is in the form of ribonucleic acid P; two-thirds of this is associated with the insoluble fibre fraction. Deoxyribonucleic acid P accounts for about 7 per cent and lipid P for 15 per cent of the total P in the leaf.

When leaf fibre or a chloroplast suspension is incubated, up to 80 per cent of the total P becomes soluble; this liberation is activated by salts, especially citrate, and there is every reason to think that it is due to the fission of nucleoprotein which also occurs as a sedimentable component of fresh sap. Using purified nucleoprotein preparations an attempt is being made to discover whether ribonuclease alone can bring about the fission or whether preliminary separation of nucleic acid from protein by another enzyme is necessary. Leaf ribonuclease does not catalyse precisely the same action as pancreatic ribonuclease, for the former converts the whole of a sample of yeast nucleic acid into an acid soluble form, whereas the latter leaves a resistant core. So that it can be used as a tool for further investigation of the nucleoproteins of the leaf, we have begun to fractionate leaf ribonuclease.

Technological Production of Leaf Protein

(M. L. Barnes, D. S. Miller and N. W. Pirie)

This work has been carried out for three years at the Grassland Research Station on a grant to Rothamsted. It is now becoming part of the work of the Grassland Research Station and will no longer be financed through Rothamsted.

During the year we have made large quantities of protein from various crops for chicken feeding experiments and have supplied leaf residue from which much of the protein has been removed, to the Rowett Research Institute. It will be used there for sheep feeding experiments.

Our arrangements for grinding leaves are fairly satisfactory, but we still have trouble in pressing out the juice from the ground mass. Several improvements have been made during the year and a press working on an entirely new principle is now being made for us at the National Institute for Agricultural Engineering.

Manganese Oxidation and Enzyme Systems producing Hydrogen Peroxide

(R. H. Kenten and P. J. G. Mann)

Work has been continued on oxidation of Mn^{++} by plant extracts and on enzyme systems producing H_2O_2 which may be associated with this oxidation. The oxidation of Mn^{++} has not yet been demonstrated in the plant *in vivo* under normal conditions of manganese supply. In experiments with plants grown in culture solutions of high Mn^{++} content, colorimetric evidence has been obtained suggesting the accumulation of higher valency forms of manganese in the tissues. The work on the reconstruction from partially purified enzyme preparations of the type of system causing oxidation of Mn^{++} in plant extracts has now been completed. When the oxidation is brought about by peroxidase systems with added H_2O_2 the oxidation product, in orthophosphate media, is reduced by the H_2O_2 as rapidly as it is formed. If, instead of adding H_2O_2, enzyme systems such as the amine oxidase D-amino-acid oxidase are used to maintain a suitably low concentration of H_2O_2, the oxidation product accumulates quantitatively. Under these conditions it would therefore be available in the plant for the oxidation of metabolites other than H_2O_2. During the course of these experiments it was found that peroxidase, coupled with plant α-hydroxy-acid oxidase preparations with lactate or glycollate as substrate, oxidized Mn^{++}, suggesting that α-hydroxy-acid oxidase systems produce H_2O_2. This has now been demonstrated by more conventional methods. Using α-hydroxy-acid oxidase preparations of low catalatic activity with lactate and glycollate as substrates, H_2O_2 production can be shown by the effect of catalase on the O_2 uptake. H_2O_2 does not accumulate. In absence of catalase it reacts non-enzymically with the products of the enzyme catalysed reactions—pyruvate and glyoxylate—to give acetate and formate respectively.

While evidence is accumulating that Mn^{++} is oxidized in higher plants, it is not yet known what plant metabolites reduce the oxidation product. In this connection preliminary results suggest that the known oxidation of dihydroxymaleate in presence of Mn^{++} and peroxidase or compounds of peroxidatic activity depends on the oxidation of Mn^{++} and the known oxidative decarboxylations of oxaloacetate and oxalosuccinate by plant tissue preparations are due to the presence of peroxidase and likewise depend on oxidation of Mn^{++}.

The Properties of the Resistant Parts of Fungal Mycelia which would accumulate in Soil

(W. R. Smithies and M. V. Tracey)

Samples of *Penicillium griseofulvum* mycelium have been analysed with particular reference to the macromolecular components—proteins, carbohydrates and chitin. The effect of autolysis on the composition of this mycelium is being investigated. An air-dried sample which had suffered subsequent autolysis in saturated thymol solution for more than 12 months had a diminished nitrogen and protein content, and the protein was more easily dispersed in water than that from unautolysed air-dried mycelium. The carbohydrate

and chitin contents are less affected and this is probably due to the relative instability to drying of the carbohydrases and chitinase compared with the proteases. Lignin-like substances, that is material insoluble in strong H_2SO_4, have been shown to occur in many fungi, though none was detected in the *P. griseofulvum* mycelium examined. Several specimens of dark bracket fungi have been collected locally and one of these, *Ganoderma applanatum*, contains about 30 per cent of this material and it is under investigation. Water soluble polysaccharides giving viscous solutions at low concentrations have been isolated from a number of higher fungi and are being studied. The changes in composition occurring during the ripening of the fruit body of *Lycoperdon pyriforme* are being followed as in this fungus a remarkably rapid and extensive series of changes result in the breakdown of much of the structure of the fruit body. During this process a powerful chitinase can readily be prepared from material in the right stage of ripening. The spores and outer walls of the fruit-body resist the action of the hydrolytic enzymes and it is hoped to examine the basis of this resistance to enzymic attack. Using the methods developed in this department for the estimation and detection of chitinase and cellulase we have made a preliminary survey of the enzymic apparatus of a number of soil organisms. Seventeen species of earthworms were examined and all found to possess cellulase. Twelve of these were tested for chitinase and found to have it. It is tentatively concluded that these enzymes are produced, in part at least, by the earthworms themselves, though the importance of the bacterial flora of the intestine must not be forgotten. Work done on the enzymes of nematodes parasitic on plants and on fungi is described in the report of the Nematology Department. It may be added here that neither cellulase nor chitinase were detected in the non-parasitic eel worm of vinegar, *Turbatrix aceti*. It is hoped to continue this work on nematodes in collaboration with the Nematology Department and to survey the occurrence of the two enzymes in common soil bacteria and protozoa in collaboration with the Microbiology Department.

NEMATOLOGY DEPARTMENT

By T. Goodey

General

From September 3rd-14th an International Nematology Course and Symposia were held at Rothamsted Experimental Station. They were the first of their kind to be arranged for the subject of Nematology in this country, and were sponsored by the Food and Agriculture Organization of the United Nations. The instructional course, held in the laboratories of the department, September 3rd-10th, was attended by scientists from the following countries: Belgium (1), Denmark (2), Egypt (1), Eire (1), France (1), Haiti (1), Indonesia (1), Israel (1), Italy (1), Netherlands (2), South Africa (1), Sweden (2), Switzerland (2), Uganda (1).

The members of the scientific staff gave lectures and organized practical work on nematological techniques and methods. In this work, too, we had the benefit of the help of Mr. Gerald Thorne from the United States. After the course symposia were held in the Small Public Hall, Harpenden, September 11th-14th, at which most of the members of the staff contributed one or more papers on problems in plant nematology. These meetings were attended by those who had taken the instructional course and by additional scientists from some of the countries already mentioned, as well as by several British specialists. Two days were devoted to the discussion of problems connected with the potato root eelworm, *Heterodera rostochiensis*; one day was spent on a visit to Cambridge and the surrounding country to see eelworm-infested crops; and a final day was devoted to further discussion of problems connected with the stem eelworm, *Ditylenchus dipsaci*; the potato tuber eelworm, *D. destructor*; the leaf and bud eelworms, *Aphelenchoides* spp.; and the root lesion nematodes, *Pratylenchus* spp. In the making and carrying out of the necessary arrangements for the course and the symposia much valuable help was given by Mr. W. C. Moore and his staff of the Ministry of Agriculture and Fisheries Plant Pathology Laboratory, Milton Road, Harpenden. A report on the course together with the papers given at the symposia and the ensuing discussion has been prepared and was issued by F.A.O. in January 1952.

During the year four temporary workers have spent periods of a month or more in the department acquiring nematological technique. They were Miss Daphne Bishop (Imperial College of Science and Technology), Mr. Wahib Doss Hanna (Egypt), Miss F. van der Tuin (Netherlands) and Dr. J. Gallego (Spain). Mr. J. J. Hesling is at present holding an Agricultural Research Council Studentship in the department.

The Ph.D. degree of the University of London was awarded to J. Basil Goodey in July.

During a short stay in Italy Dr. T. Goodey was able to spend a few days with Prof. G. Goidanich and his staff at the Laboratory of Experimental Plant Pathology, Bologna, and to help in the diagnosis of certain eelworm infestations of hemp, wheat and various garden crops.

Research carried out by the members of the staff falls, as in

previous years, into two main divisions: (1) problems connected with plant infestation by eelworms belonging to the families Tylenchidae and Aphelenchidae and soil nematodes generally (Dr. T. Goodey, Dr. Mary T. Franklin and Dr. J. Basil Goodey); (2) problems connected with root-infesting nematodes belonging to the family Heteroderidae (Dr. B. G. Peters, Mr. D. W. Fenwick and Mr. C. C. Doncaster).

Tylenchidae and Aphelenchidae

Tylenchidae

Dr. T. Goodey continued investigations on the stem eelworm, *Ditylenchus dipsaci*, infesting oats and teasel. A number of spring oat varieties were tested, both by a laboratory method and on an experimental plot, for susceptibility to attack. It was found that the variety S.225, raised by Professor E. T. Jones of Aberystwyth, showed good resistance. This and a few other spring oat varieties which also showed signs of resistance will be tested further. Field observations made at a farm in east Hertfordshire, where susceptible oats commonly fail from stem eelworm attack, and where S.225 was being grown, confirmed the resistance of this variety, as no affected plants could be found.

Mr. M. V. Tracey, of the Biochemistry Department, using infested and uninfested oat seedlings supplied from some of the foregoing tests, found that the enzyme cellulase occurs in greater amount in infested than in healthy seedlings of the same age. He also found cellulase in the nematodes themselves.

Oats of the very susceptible variety S.147 when grown on the teasel eelworm plot were attacked by *D. dipsaci* with the production of typical " tulip root " symptoms. From this and from observations made more than 80 years ago by Kühn in Germany, who found that the stem eelworm from teasel would infest rye, it may be inferred that it is probably one and the same biological race of the parasite which will infest teasel, rye and oats.

Some small-scale tests have been made with the stem eelworm attacking hemp in order to determine the range of crop hosts which this race is capable of infesting. It is hoped by this means to afford some help to Italian plant pathologists who have asked for assistance with this problem.

Dr. J. Basil Goodey reports that work has continued chiefly on the problems connected with the parasitic species of *Ditylenchus*, the stem eelworm, *D. dipsaci*, and the tuber rot eelworm, *D. destructor*. There are various biologic races of *D. dipsaci* found in this country, some of which occur naturally in common weeds of pastures and arable land. Races are found, for instance, on *Plantago lanceolata* and *Hypochoeris radicata* growing on waste land, and experiments have been started this year with these and some other races to try to understand more of the biology of *D. dipsaci* generally and the relationship of these races to those known to cause serious damage to agricultural crops.

Field beans, *Vicia faba*, are commonly attacked by the oat race of stem eelworm when severe damage to the stem base usually results. There is also a so-called giant race of *D. dipsaci* which attacks *V. faba*. This occurs in Portugal and has also been recorded

in this country. Experiments carried out during the last few years have shown that the infestation of *V. faba* by the giant race is seed-borne to the extent of 30 per cent, while the oat race is not transmitted by seed, although occasionally, on badly attacked plants, pods are affected and eelworms have been found, in one or two instances only, closely associated with the seeds. The red clover race of stem eelworm may also attack beans at the stem base, but observations and experiments indicate that the eelworms cannot maintain themselves on this plant and die out after a time.

The stem eelworm on *Plantago lanceolata* has been found to be seedborne to a small extent. A new weed host of the oat race of *D. dipsaci* has also been discovered.

A species of *Ditylenchus* has been known for a number of years to be the causative agent of a serious disease of mushrooms. The mushroom beds begin to crop quite well and then suddenly fail. Examination shows that the mycelium has been more or less destroyed, and there is often a characteristic smell produced, reminiscent of acetylene. It has recently been shown in Holland that the eelworm responsible for this damage is *D. destructor*. Work on this problem has been carried out in this department during the past year and observations which have been made on numerous samples of compost from diseased mushroom beds have confirmed the identification of the eelworm. Experiments attempting the transfer of the eelworms from compost to potatoes and mint have all failed so far. The work is continuing. In this connection it may be mentioned that M. V. Tracey of the Biochemistry Department has shown that chitinase is present in *D. destructor* infesting mushroom compost.

Studies have continued on various aspects of the host range of *D. destructor*; in particular the influence of the host plant on the parasite. Considerable variation in size, body ratios and growth of gonads occurs; variation which is so striking as to possibly warrant the view that more than one species of *Ditylenchus* may be involved. This view is, however, untenable since a study of the anatomy of the eelworms and evidence from host transfer experiments shows that all the eelworms are *D. destructor*.

Observations have continued on *Hoplolaimus uniformis* and a species of *Trichodorus* associated with the roots of Sitka spruce, *Picea sitchensis*. The numbers of eelworms present actually attacking or in close proximity to the roots are small and variable, and it is too early to be able to say what effect, if any, they have on the young seedlings. This work has been done in co-operation with the Chemistry Department. Further work is contemplated designed to investigate the relationships between these eelworms and Sitka seedlings. Recent work in Florida, U.S.A., has shown that a species of *Trichodorus* is responsible for a stubby-rooted condition of a wide range of vegetable crops. It is interesting, therefore, that *Trichodorus*, which has hitherto been considered a free-living nematode, has been encountered attacking roots of Sitka in this country.

During the year help was sought by the Cameroons Development Corporation in the identification of eelworms associated with a root disease of *Elaeis guinensis*, the oil palm. A species of *Hoplolaimus*, new to science, was discovered which has several remarkable features

as an eelworm. It is closely related to *H. coronatus*, which is known as a root parasite in the United States. Only comparatively few eelworms were associated with each root system, and they were found attacking the short lateral roots, causing considerable damage to the cortex. It appears unlikely that the eelworms themselves are responsible for all the disease symptoms shown by the seedlings, but more probable that the lesions they cause are the ports through which fungi or other pathogens enter and set up more serious damage.

Aphelenchidae

Dr. Mary T. Franklin reports that observations have continued on black-currant bud disease caused by *Aphelenchoides ribes*. Blackcurrant cuttings treated in November with warm water for killing the eelworms in the buds, and subsequently planted out of doors, failed to root. This was largely because the treatment caused premature expansion of the buds which were then destroyed by frost. Further examination of weeds growing amongst infested bushes have shown many of them to be carriers of the eelworm.

Investigations of the effect on blackcurrant eelworm of spraying infested bushes with Parathion have been made in co-operation with Mr. Brown of the National Agricultural Advisory Service, Cambridge. The results will not be available before next season, but do not appear to be very promising.

The nematode found last year attacking Caucasian scabious, and at first thought to be *Aphelenchoides parietinus*, has now been described as a new species, *Aphelenchoides blastophthorus* (="bud destroyer"). It has been found in scabious from 13 nurseries in various parts of England and one in Scotland. So far it has only been found in *Scabiosa caucasica* var. Clive Greaves. Seedlings of other varieties have been grown and inoculated to find out whether they are susceptible.

As *A. blastophthorus* was at first confused with *A. parietinus*, further attempts have been made to obtain *A. parietinus* from its original habitat in the lichen, *Xanthoria parietina*, at Broadmoor, Berks. The nematode was not described originally in sufficient detail and only the female was found by Bastian in 1865. It is thought that nematodes identified as *A. parietinus* and described sometimes as plant parasites and sometimes as saprophytes may belong to different species and may not all be identifiable with true *parietinus*. It is therefore necessary to have a detailed description of the true *A. parietinus* in order to clarify the situation. So far no males of the species have been found, and it is now thought that, at least in this habitat, the nematode may be parthenogenetic. It is being cultured on agar with a fungus in the hope that males may be produced. During the examination of lichens other interesting nematodes have been found, though they are probably of no practical importance.

HETERODERIDAE

Dr. B. G. Peters reports that the pot experiments to test the effects on *Heterodera rostochiensis* of various edaphic factors (sand, peat, compost and artificials) reached its second year in 1950. Analysis of the data showed that the density of eelworm larvae per gramme of soil (1/g) had decreased, after a 35-fold increase in the

first season. Positive effects were found for peat, compost and artificials, with no significant interactions. This index of larval density is the product of cyst density (c/g) and the mean number of larvae per cyst (l/c) ; the latter criterion showed no treatment effects in the first season, but in the second there was a positive compost effect with three negative interactions suggesting that peat interferes with the stimulating effects of the other factors.

The indication that the larval density had already reached saturation, and the lack of significance in plant criteria (height of haulms and weight of crop), led to the decision to discontinue the experiment. In its place, a new experiment has been set up in which eelworm infestation has been made a factor (i.e. it is omitted from half the pots) and has been introduced at the much lower density of 0·01 cysts per gramme of soil. This has run through its first season, but counts have not yet been made.

Pot tests of nematicides to control potato root eelworm are carried out each year. Counting of cysts and larvae, and analysis, of the 1950 samples have shown kills above 95 per cent for methallyl chloride at 16 ml. per 20 lb. soil and for the following at either 4 or 16 ml. : D-D mixture, ethylene dibromide, and bis-chloroethyl ether. D-D appears to be slightly more effective when formulated as an emulsion in water (poured over the soil as a drench) than when injected without water. A commercial preparation of phenols was not very effective against this particular eelworm. Phytotoxic effects were marked from ethylene dibromide and slight from bis-chloroethyl ether, but the potato plants appeared to be stimulated by methallyl chloride and D-D at the lower rate (4 ml. per 20 lb.).

During the current season similar tests have been carried out using D-D, bromochloropropylene, iodine, chlorophenols, chloro-isothiocyanates, chloronitrobenzenes, Parathion, and ammoniacal gas liquor. Counts are not yet available.

Analysis of the 1950 data on the vertical migration of *H. rostochiensis* larvae through soil (in boxes composed of 2-inch layers) shows that more than 80 per cent of the new cysts produced remain within two inches of the original inoculum, whether that was placed at the top or at the bottom of the box. Migration (up or down) of six inches or more was achieved by about 1 per cent of larvae. Half the boxes were under glass and half outside in the shade. In the latter, multiplication of cysts was twice as high from top inoculation as from bottom ; in the boxes under glass there was a very slight multiplication from top inoculation, but bottom inoculation gave a multiplication almost as great as top inoculation in the shade. This probably indicates that insolation under glass is lethal to larvae in the upper layers of soil, but those in the lower layers benefit from the higher glasshouse temperatures.

The sectional boxes just mentioned have been used during the current season filled with infested soil and each planted with a potato. The boxes have been dismantled, in pairs, at four different times during the season in order to follow changes in larval population at various depths. Counts are not yet available.

Among minor activities may be mentioned the examination of six samples of potato soil from Norway. No potato eelworm was found. Norway is now the only country in north-western Europe

from which the parasite has not been recorded. In growing a potato in a glass-sided box (to study migration of eelworm from a 1-inch layer of infested soil, sandwiched between uninfested layers), males of *H. rostochiensis* have been seen on two occasions: first in June, 63 days after planting, and secondly in September, 43 days after a second planting in fresh soil. The long time elapsing before parasites were seen is probably due to the cool spring.

Mr. Fenwick co-operated in a joint experiment with the West Norfolk Farmers' Co-operative and Shell Chemicals Ltd., in which D-D mixture was injected annually for three years into field plots infested with *H. rostochiensis*. Potatoes were grown each year. The experiment finished in the autumn of 1950, but the final counts were not available in time for the last report. Briefly, the results show that on a silt soil at Moulton D-D led to an increased yield of tubers sufficient to have paid for the treatment, without any cumulative build-up of the eelworm population. On a black fen soil at Prickwillow D-D led to a significant net increase in the eelworm population with no economic increase in yield. It seems evident that the type of soil largely controls the efficacy of this fumigant.

During the current year the same co-operators have started a new experiment near Wisbech, in which D-D is being injected at various stages in a five-course rotation and is to be repeated on some plots for 2-5 years. This year each of the 30 plots has been sampled, potato yields have been recorded, and the first injections have been made. It is planned to sample the plots for eelworm population changes each autumn, and again for assessment of nematicidal effect each spring.

Mr. D. W. Fenwick reports that experiments on the bio-assay of root diffusate are now completed. Disappointing results from experiments with synthetic chemicals as standards for comparison led to the investigation of purely biological phenomena. Three sets of relationships have been established. If a sample of diffusate be progressively diluted in a logarithmic series the activity falls off in a linear manner so that it is reasonable to assume that the activity of each dilution is proportional to the logarithm of its concentration. If cysts from different stocks are exposed to such a series of dilutions, the linear regression lines obtained when extrapolated to a level of hatch equivalent to that in water all give a similar dilution value indicating the existence of a threshold of concentration below which any diffusate is inactive. If similar dilutions of different diffusates act on cysts from a single stock the curves for each diffusate are parallel to one another, making it possible to express the activity of one in terms of that of any other. The threshold value of dilution furnishes a convenient reference point for any diffusate from which its original value can be calculated if tothe threshold concentration is ascribed a value of one arbitrary unit of concentration. It is proposed to express concentration logarithmically and the term L.A. is proposed; the L.A. of any diffusate being defined as the logarithm of its concentration in arbitrary units. It is an arithmetic measure of its activity in terms of larval emergence. The work is in process of being written up for publication.

The above technique has rendered possible the conduct of experiments on the factors influencing the production of root diffusate by

plants. An experiment on the relationship of age and diffusate production using Arran Banner potatoes shows that maximum production of diffusate occurs at an age of 2-3 weeks. Preliminary examination of the data indicates that this was the period of maximum growth of the experimental plants and it seems reasonably safe to say that production is positively correlated with the rate of growth of roots. Rate of growth is apparently far more important than root mass. Experiments on the influence of potato variety on diffusate production indicate that the maximum varietal differences are shown very early on in the plant's life ; later the differences become less and less significant. It is considered that these differences in the early stages are a reflection of increased rate of growth in the first few weeks and thus confirm the results of the experiment on root diffusate production and age. Investigations have been carried out on the effect of infestation with *H. rostochiensis* on root diffusate production and although not complete there is reason for believing that the plant response to infestation is the production of an increased quantity of diffusate. This is considered to be further confirmation of the correlation between root diffusate production and growth rate since the normal reaction of plants to infestation is the production of new roots to replace infected ones.

To expedite the setting up of hatching tests, experiments in conjunction with Miss Reid have been carried out on the errors attendant on weighing equal-sized batches of cysts instead of counting. Using a capillary micro-balance the increased error is so small that it can be ignored and the method is now in standard use. It has been written for publication.

A series of experiments, in conjunction with Professor Todd of Cambridge and Professor Stoughton of Reading, sponsored by the Agricultural Research Council, have been commenced to elucidate the activity of the stimulatory factor in tomato root diffusate. Apart from routine testing of samples and fractions, work has been conducted on the effect of different adsorption rates with animal charcoal on residual activity of diffusate and interesting results have been obtained. Experiments are also in progress on the temperature stability of different fractions.

Tests on the break-down of potato root diffusate have been continuing but as yet they are not sufficiently advanced to give definite results.

Studies on population changes during the growth of potatoes have been continued. A trial was carried out in which ten varieties of potatoes were first grown in infested and then transplanted to clean soil. It was found that the maximum invasion occurred in the case of early varieties. The cysts produced had fewer larvae, however, although the reduction in larvae per cyst was not sufficient to offset the increased invasion. A further experiment was carried out to investigate the gross reproduction rate of eelworm on the same ten varieties at three levels of infestation but results of this experiment are not yet available.

Co-operation with Dr. H. C. Gough of the Cambridge National Agricultural Advisory Service on long-term changes in eelworm population during crop rotations on different soils is still continuing.

Mr. C. C. Doncaster reports that a six-year plot experiment has been started in order to investigate the effect on a long-standing population of *Heterodera rostochiensis* of four different three-course crop rotations, each one including potatoes. The numbers of *Heterodera* cysts are to be estimated in soil samples from each plot once each year and the yields of potatoes will also be recorded.

Investigations on the susceptibility of *Solanum nigrum* to attack by *Heterodera rostochiensis* have shown that though larvae of the eelworm will readily penetrate the roots, they are generally unable to develop. Occasionally, seven weeks or so after invasion, abnormal and degenerating larvae are to be found corresponding to a stage which is normally reached in potato roots about ten days after invasion.

Solanum nigrum suffers more serious root necrosis than do tomatoes or potatoes.

It was found possible to infest *Solanum nigrum* and tomatoes with *Heterodera rostochiensis* in two days and the plants were transferred to clean soil and lifted at subsequent intervals. Roots were collected for histological examinations of infestations of known age.

A comparison has been made between *Solanum nigrum* and tomatoes growing in soil with four levels of *Heterodera* in inoculation ranging from zero to 180 larvae per g. of soil. Plants were lifted after one week, two weeks, four weeks and eight weeks.

Solanum nigrum appeared to show a progressive decline in its rate of growth as the eelworm infestation increased. The effect on tomato was more complex : there appeared to be a stimulating effect at low rates of infestation but at high rates an inhibition of growth occurred even more serious than that suffered by *Solanum nigrum*.

The activity of the root diffusates of the two plants appeared to be generally comparable. In *Solanum nigrum* during the first and second week before growth is noticeably retarded there appears to be a decline in root diffusate production; its activity being about 50 per cent of that of the uninfested controls, but at eight weeks, when growth is seriously checked by eelworm invasion, root diffusate is as active from infested plants as from uninfested ones.

Tomato, in its early stages of growth, produces root diffusate of greater activity as the infestation increases until at 180 larvae per g. of soil there is about a 50 per cent increase in activity. At the later stages, growth and root diffusate activity are both reduced by this infestation, the diffusate being about three-quarters as active as that from the controls.

The overall effect in *Solanum nigrum* is a decline in root diffusate production with increased soil until at 180 larvae per g. infestation the activity falls to about two-thirds of that obtained from control plants.

Cysts have been recovered from soil in which tomatoes and *Solanum nigrum* have been grown and the effect of the plants upon the cyst-contents is being determined.

ENTOMOLOGY DEPARTMENT

By C. B. Williams

The work of this department continued during 1951 on the lines of previous years with little change except that Mr. Banks resumed his work on Aphid predators and Mr. Murphy replaced Dr. Evans in the work on Forest Soil Arthropods.

Effect of Weather Conditions on Insects

(C. B. Williams, R. A. French, B. P. Singh and M. M. Hosni)

Trapping during 1951 has been carried on by two light traps and two suction traps. The light traps were of a new mercury-vapour type rich in ultra-violet light, which had been shown by experiments last year to be considerably more efficient than the type that we had previously used. One of the new traps placed in the garden of the Manor House caught 26,000 Macro-lepidoptera between March and November 1951, as compared with an average of about 4,000 per year in previous years with the older type of trap.

The use of one light trap inside a wood and the other outside has enabled us to measure the effect of trees in damping down the micro-climatic changes as compared with outside.

One suction trap has been working near each light trap so that we have a comparison of the two environments with two types of traps. The suction traps have also been working for two hours each day—from 12-2 p.m.—so that we have for the first time a measure of day-time activity for study in relation to day weather.

A preliminary experiment in 1950 had shown evidence that about four times as many insects were captured in a suction trap at night at the period of new moon as at full moon. Results obtained from the suction traps in 1951 confirmed this result in the case of the trap inside the woodland, but the trap outside showed no significant periodicity.

Mr. B. P. Singh is writing up the results of his two years' work with suction traps as a thesis for a London Ph.D. degree. His quantitative estimates of the effect of various weather conditions on insect activity agree closely with those previously obtained by the use of light traps. This considerably increases the reliance that can be placed on both sets of calculations.

Relative Abundance of Different Species of Insects

(C. B. Williams)

An analysis of very large catches of insects—such as has been obtained from our new mercury-vapour traps in 1951—shows that the relative abundance of different species corresponds more to the log-normal distribution than to the logarithmic series. A paper on this problem is almost ready for publication. The mathematical problems involved have been studied by Dr. P. Grundy of the Statistical Department (q.v.).

Insect Migration

(C. B. Williams and R. A French)

Records continue to come in from all parts of the world—and Rothamsted also receives each year for study and storage several thousand records collected by the Insect Immigration Committee of the British Isles.

Attention has been focussed in recent years on the problem of the return flight to the south in autumn in species which are known to move north in the spring. An examination of more than a thousand records in our files show that there is definite evidence of a southerly autumn movement in at least four of our British butterflies : the *Vanessa atalanta*, *Vanessa urticae*, *Colias edusa* and *Colias hyale*. The discovery of evidence for the movement of *V. urticae* is particularly interesting as although there were a few records suggesting the possibility of migration in the Continent, we had not previously considered the insect to be an immigrant into Britain.

G. F. Cockbill—who worked at Rothamsted about 10 years ago —has just published an account of the migrations of *Catopsilia florella* in Southern Rhodesia, and there also he finds evidence of a reversal of direction at different seasons.

The Effect of the Population Density on Lepidopterous Larvae

(D. B. Long)

Last year it was shown that the larvae of the Silver-Y Moth (*Plusia gamma*) reacted to the larval population density. When they were bred under solitary conditions the larvae were typically light green but when bred under crowded conditions much darker forms were produced as well.

Due to the late spring it was possible to investigate the larval response of only a few additional species. Whereas the migrant Silver-Y Moth had shown a definite response, no obvious results were obtained with the larvae of the migrant Cabbage White Butterfly. On the other hand, definite colour variants were produced in the larvae of the non-migrant Emperor Moth (*Saturnia pavonia*) and in certain non-migrant species of the genus *Orthosia* (Family Noctuidae).

In the case of the Silver-Y Moth further work has been done on the relative rates of development of larvae bred under solitary and crowded conditions. " Crowded " larvae grow at a more uniform rate and complete their development much more rapidly than do solitary larvae. This appears, in part, to be related to the number of moults which the respective larvae undergo. There has been some evidence to suggest that the relative frequencies of the dark and light forms in the crowds is dependent on a genetic factor. In order to investigate this, a heated greenhouse has been erected and selected breeding lines are being set up.

The Distribution of Aphids by Wind

(C. G Johnson and L. R. Taylor)

The work at Cardington on aerial dispersal of insects continues. It is found that, on the average, there is an approximately linear relation of log. aphid density to log. altitude ; this enables curves

of density on height to be integrated. Thus it is possible to estimate not only the density at different heights but the total number of insects in a zone of air. This shows that, in general, by far the greater proportion of aphids flying during the day are at altitudes above 100 feet and thus subject to dispersal by air currents. The consequences of this in the ecology of the insect are being studied together with work on rates of elevation and deposition.

Factors influencing changes in aerial numbers of aphids at crop levels

The first stage of an intensive study of changing aerial densities of bean aphis (*A. fabae*) at crop level has now been completed, with an analysis of the roles of population change and flight activity as influenced by current meteorological conditions.

In the past great stress has been placed on the importance of wind, temperature, humidity, etc., as factors regulating aphid flight. It is now clear, however, that changes in the level of alate populations which take place with a rapidity not hitherto appreciated can outweigh in importance the changes in current meteorological factors, and that factors of population rather than of flight behaviour are of primary significance in regulating numbers of aphids in the air even from one half day to another.

Statistical techniques and estimation of aphid numbers

For some time now work has been in progress in producing a suitable method for counting large numbers of aphids by sampling aliquot parts of a bulk suspension.

The statistical side has been in the hands of Mr. J. A. Nelder of the Vegetable Research Station, Wellesbourne.

An apparatus has now been devised and perfected on which by counting a small fixed number of aphids it is possible to estimate numbers from 1,000 to 20,000 within $\pm$ 7 per cent fiducial limits in about five minutes.

Design and refinements of suction traps

In using suction traps it has been assumed that, with aphids, the numbers caught varies directly with the volumetric flow of the trap. There are, however, errors in this, particularly those associated with the increased momentum of insects as they traverse the trap in winds of different velocities. Attempts to assess these errors are being made in conjunction with the Aerodynamic Section of Blackburn and General Aircraft Co. Ltd.

Infestation patterns

The pattern of infestation of bean fields infested with *Aphis fabae* has been shown to follow, in some cases, the direction of the wind during primary migration. Work on this problem has continued in collaboration with Mr. C. E. Taylor of Sutton Bonington.

The Natural Enemies of Aphids

(C. J. Banks)

Not much is known about the effects of an enemy population on an aphid population, or of its ability to control or prevent outbreaks of aphids. Work was started on this problem in the summer

of 1951. Enemies of the Black Bean aphid, *Aphis fabae* Scop. were studied, for not only is this insect of economic importance but its ecology is being studied in this department.

There were two initial problems: first, to record the various species of enemies and second, to estimate their numbers in relation to the varying numbers of aphids present. Special sampling techniques will have to be developed for estimating degrees of parasitisation, and therefore, for the time being, quantitative methods have been concerned mainly with the predators, which include lady-bird beetles, hover-fly larvae, lacewings, Anthocoridae and mites.

A detailed study of a bean crop was carried out, using three methods of sampling: (1) The suction trap method has given information on the abundance of flying predators such as lady-birds, hover-flies and lacewings. (2) The removal from the crop of 40-50 infested stems each week during the infestation has provided information on the numbers of aphids present on stems and the numbers of predators associated with them. This method has, so far, proved satisfactory only for hover-fly larvae (Syrphidae). (3) Weekly field-counts of predators and their eggs on a large number of stems have provided data which could not have been obtained by any of the other methods. Errors of sampling have been estimated and the reliability of the methods assessed. No single method is of general application and future work will have to include all three with improved techniques.

Two of the main problems encountered in the investigations are that the natural enemies are few in total numbers, especially when compared with the numbers of their prey, and that many of them tend to aggregate on the infested stems. The pronounced aggregation of hover-fly eggs on infested stems suggests that the female flies are attracted to the aphids, and this is a problem which will be investigated in the coming year.

Population Studies

(H. F. Barnes)

The expected fifth peak of the two wheat blossom midges in 1951 was masked on Broadbalk owing to the failure locally of the appearance of the wheat ears to coincide exactly with the emergence of the midges. But serious outbreaks did occur in S. Ireland and Yugo-Slavia (on rye) while news has been received of serious damage occurring in China.

S. mosellana larvae collected each year (except 1947) since 1939 inclusive have been successfully rear during 1951 thus demonstrating the probability of fully grown larvae of this species surviving twelve winters in the soil. Mr. G. H. Golightly of the National Agricultural Advisory Service, Northern Province, has this year obtained figures showing that *S. mosellana* does survive in the soil under field conditions for at least seven winters.

The twenty-fifth successive year of sampling Broadbalk for wheat blossom midge has now been completed.

Gall Midges of Economic Importance

(H. F. Barnes and Miss B. M. Stokes)

Vol. 5 of Dr. Barnes' monograph on gall midges of economic importance was published during February. This volume which deals with the gall midges of trees thus appeared after Vol. 6, which was published in 1949. The final preparation of Vol. 7 which will deal with the gall midges of cereals has been delayed so that it may contain a full account of the wheat blossom midges as they have occurred on Broadbalk during the last quarter of a century (1927-51).

Enquiries concerning the identification and control of gall midges have continued to come in from all over the world. Noteworthy among these has been a serious outbreak of *Contarinia chrysanthemi* Kieffer attacking Shasta Daisy in the north of England. This is an instance of a change of host plant from a weed (Ox-eye Daisy) to a cultivated plant and emphasizes, if necessary, the importance of the studies on host plant range of gall midges that are being undertaken. Other gall midges attacking willow, mushrooms, rose, apple, peas, wheat and oats have been sent in. An interesting discovery of *Camptodiplosis* sp. living on Jew's Ear Fungus (*Auricularia auricula-judae*) has been made by Professor P. A. Buxton. Other notable consignments of gall midges have been received from Madagascar, India and Yugo-Slavia.

Miss Stokes' investigations into the host plant range of the swede midge is nearing completion. Considerable advance has been made in an investigation of the biology of a gall midge whose larvae feed in the overwintering flower buds of elm and form part of the winter and spring food of tits. Comparison with newly acquired larval specimens of a somewhat similar American species has shown that the two species are distinct. During the year two families of the Hessian Fly were successfully reared and demonstrated that unisexual families in this species occur in this country as had been previously shown to exist in the United States. Dr. Barnes has now personally reared all the species of gall midges in which this phenomenon is known to occur.

Slugs

(H. F. Barnes and Miss B. M. Stokes)

The garden studies of slugs have been largely in abeyance during 1951. Miss Stokes has continued her laboratory study of the biology of *Testacella* and should be writing up her results in the near future.

Wireworms

(F. Raw and J. W. Stephenson)

The wireworm population studies on the Ley and Arable Experiment on Highfield and Fosters have been continued. Samples were taken in March and September, 1951, and now that the experiment is fully established the full complement of plots from both fields was sampled. The examination of the samples and the material extracted from them has formed a major part of the year's work. At least one further year's sampling will be necessary before a detailed analysis of results will be possible but already there are clear indications of consistent differences in the wireworm

populations of the various leys. As the movements and oviposition preferences of the adults are likely to cause these differences it is hoped to study these factors in the coming spring and summer.

The wireworm experiment on Little Hoos has now been ended. A final sampling made in September, 1950, showed that the differences in wireworm population between the plots were consistent with the assessment of the immediate and residual effect of the treatments as measured by crop yield. Gammexane 3·5 per cent dust broadcast at 2 cwt. per acre and combine-drilled at $\frac{3}{4}$ cwt. per acre, and 41 per cent ethylene dibromide injected at 15 gall. per acre had given good immediate and residual effects. The wireworm population of these plots was greatly reduced. It was also greatly reduced on the plots in which 5 per cent D.D.T. dust had been combine-drilled. This treatment, though not having such good immediate effect as the previous three, had had a good residual effect. The populations of the plots injected with D.D. at 400 lb. per acre, and those in which the seed was treated with gammexane seed dressing showed little or no difference from the controls. These treatments, though having an immediate effect, had shown no residual effect.

Park Grass

The sampling of selected plots on Park Grass to study the distribution of the soil fauna has been continued. One of the most interesting results so far concerns the abundance and distribution of Protura. These primitive insects generally considered rare have been found in great numbers in some of the plots (as many as 400 individuals have been found in a single soil sample 2 in. diameter and 9 in. deep). Their abundance is strongly correlated with pH, being greatest on the more alkaline plots. From the data so far collected it is not possible to decide whether pH is itself the causative factor or whether other factors correlated with pH are responsible.

Earthworms

(J. E. Satchell)

Progress has been made in developing the electrical sampling method for quantitative work. A water cooled electrode has been developed whereby the fall in current due to heating and consequent drying out of the soil has been reduced. Using this electrode and by stepping up the current at intervals the sampling area can be increased and the errors due to surface species, e.g. *A. chlorotica*, coming up much nearer the electrode than deeper living species, e.g. *L. terrestris*, have been reduced.

In April 1951 selected plots on Park Grass were sampled. Four sampling points were taken in each plot and the worms which surfaced in 40 minutes were collected. Of the eight species present *A. caliginosa*, *L. castaneus*, and *E. rosea* were dominant. The greatest numbers were found on the limed halves of plots 7 and 13. Only occasional worms were found on the very acid plots 4_2 and 11_1. Below pH 4·5 abundance was strongly correlated with pH but above pH 4.5 no clear relationship was evident. *L. castaneus* showed the greatest tolerance of acidity. The work of seeking to relate the

distribution of the various species to other physical and biotic factors is being continued.

Staff

Dr. G. O. Evans resigned from his work for the Forestry Commission on Soil Arthropods, and Mr. P. Murphy was appointed in his place.

Mr. M. M. Hosni of Egypt came as a voluntary worker in January 1951 for two years.

Mr. B. R. Laurence resigned from the Agricultural Research Council scholarship which he had held at Rothamsted for nearly two years.

Dr. Williams, Dr. Barnes, Dr. Johnson and Dr. Raw officially attended the 9th International Congress of Entomology at Amsterdam, and in addition Mr. French, Mr. Long and Mr. Hosni attended privately.

Dr. Williams was invited to give an address to the full Congress on "The International Aspects of Insect Migration and Insect Drift" and also to provide a paper at the Symposium on Insect Phenology.

Dr. Barnes was invited to be Chairman of the Symposium of Insect Phenology and to contribute the opening paper.

Dr. Johnson also read a paper on the Distribution of Aphids.

During the Congress the Netherlands Entomological Society elected Dr. Williams as an honorary member.

Dr. Barnes has been invited to serve on the Editorial board of "Marcellia"—the International Journal for the study of Plant-Galls.

Visiting Scientists

Mr. W. S. Volkers of the University of Utrecht, Holland, spent two weeks in June and July studying problems of population statistics with Dr. Williams.

Mr. W. C. Nijveldt, also from Holland, spent a few weeks in the department in October to study problems of Gall Midges with Dr. Barnes and Miss Stokes.

BEE DEPARTMENT

By C. G. Butler

General

Lectures have again been given by several members of the department to Scientific Societies, Beekeepers' Associations and other organizations.

Members of the department have also taken a major part in conducting an Extension Course, arranged by London University, on " The Honeybee and some other Social Insects and their Allies ".

Three members of the department attended the Fourteenth International Beekeeping Congress at Leamington Spa; and a successful three-day International Conference of bee research workers, the first of its kind, was organized and held at Rothamsted in September. More than 40 workers from 14 different countries attended this Conference.

During the year Mr. L. Bailey joined the scientific staff and has commenced work on Nosema disease. Miss G. R. Wykes has obtained her Ph.D. degree of London University. The Agricultural Research Council has extended their grant to Dr. Wykes to enable her to continue to work on problems of nectar secretion for a further year. Mr. J. B. Free, who also holds a grant from the Agricultural Research Council, has joined the staff to work on the behaviour of bumblebees, with particular reference to the pollination of red clover.

Dr. C. G. Butler has continued to serve on various Committees such as the Ministry's Bee Disease Advisory Committee, and their Honey Marketing Standards Committee.

During the summer a film illustrating the technique of instrumental insemination and bee breeding employed in the department, entitled " Breeding Better Bees ", in which Dr. Butler, Mr. Simpson and Miss Carlisle took part, was made by Mr. C. P. Abbott. This film was first shown at the Fourteenth International Beekeeping Congress.

Bee Behaviour

General

Dr. C. G. Butler has now published the results of some of his work on the important part played by floral perfume in the discovery of both new and previously visited sources of food by the worker honeybee (129). He has been able to demonstrate that there is a natural tendency for untrained scouting bees to associate certain perfumes, such as those of the flowers of hawthorn and white clover, with food, whereas the perfumes of the flowers of some other species of plants, such as *Spirea arguta*, are either ignored by, or perhaps even repellent to, the honeybee.

Normally floral perfumes are rather weak and, since the acuity of the worker honeybee's sense of smell is similar to that of man (von Frisch, 1919), a foraging bee has to approach a flower very closely before she can appreciate its scent. If a honeybee is attracted towards an object, such as a real or an artificial flower, by its colour, pattern, movement and other characteristics, she exhibits a graded

series of patterns of behaviour. At one end of the scale she merely departs from her characteristic searching, weaving, flight for a sufficient period of time to swerve down towards the object and inspect it more closely before continuing her flight as before. At the other end of the scale she settles on the object after some preliminary hovering and seeks food with extended tongue from any small crevice it may contain. In general the results of these investigations with both trained and untrained bees support the conclusions reached by Professor von Frisch in his work with trained bees, and indicate that, as a general rule, such floral characteristics as colour and pattern attract a bee from a distance, and that when the bee has made a close approach floral perfume stimulates her to make an even closer inspection. Sometimes, however, when the scent of a crop of flowers is really strong it does serve to attract bees from a distance under conditions in which the crop is invisible.

The nature of the behaviour that was observed probably explains the apparent temporary repellent effect to bees of certain insecticidal sprays when they are applied to open flowers on which the bees have been working.

Mr. C. R. Ribbands has, in collaboration with Dr. H. Kalmus of University College, London, also found that odours, but in this case odours produced by the bees themselves, play an important part in communication between honeybees that are visiting and seeking dishes of sugar syrup in the field. The results of this investigation are now being prepared for publication.

Mr. C. R. Ribbands has also been studying the question of colony organization and has shown that the age of honeybees is not the controlling factor in the determination of the division of labour amongst the worker bees of a colony. It was then postulated that food is the operative mechanism, on the ground that the total food supply of a colony determines the proportion of its workers which are required for each task. This hypothesis was tested, in collaboration with Mr. H. L. Nixon of the Plant Pathology Department, by means of experiments designed to measure, by the use of a radioactive tracer, the extent of food transmission within the colony. It was shown that this is very thorough and speedy, and it is considered to be sufficient to account for the division of labour. The results of this work are being prepared for publication.

Further studies on the foraging behaviour of individual honeybees have been made by Mr. Ribbands and Miss A. Speirs.

Dr. C. G. Butler, Mr. J. B. Free and Miss E. Tyndale-Biscoe have made a series of observations on the behaviour of guard and other bees of a colony at their hive entrance on the approach of robber wasps, robber bees from another colony, straying bees from another colony, and of other members of their colony. They have also studied the effect of the behaviour of those bees whose hive is being approached in this way on the behaviour of the wasps and various categories of bees mentioned. It is hoped that these results may perhaps throw some light on the problems involved in uniting colonies of bees and in queen introduction. A paper giving the results of these experiments is being prepared.

Egg laying, swarming, etc.

Miss E. Carlisle has made observations on the egg-laying activities of a queen honeybee throughout an eleven-week period from June to September. The distance covered by the queen, the frequency and duration of egg-laying, feeding and resting times were all noted throughout one- or two-hour periods, on consecutive or alternate days at first, and later twice a week. No system was apparent in the method of filling a comb with eggs: in one two-hour period during which 91 eggs were laid, the queen covered a large part of the comb in a random manner, and moved from one face to the other nine times, with six resting and feeding periods of three to eight minutes. Not until one comb was nearly filled with eggs did the queen move to another. When all the combs were nearly filled with brood or stores of food, the queen became either very agitated and moved actively from one to another seeking empty cells or else remained inactive for long periods before moving slowly for short distances.

Mr. J. Simpson has been making observations on the behaviour of the bees of a colony before and after swarming. A colony of bees that is about to swarm shows reduced activity in comb building, foraging and the rearing of brood. Queen cells are also present. The swarm from such a colony, although it consists entirely of bees from that colony and has the same queen as was present in the colony before swarming took place, immediately becomes fully active and does not rear further queen cells. Knowledge of the reasons for this change in behaviour is necessary for the understanding of the processes culminating in swarming. The act of swarming does not in itself bring about the change since if the swarm is returned to the parent colony it will usually emerge again in due course. The effect is likely therefore to be due to the separation of the bees of the swarm from something present in the colony from which they come. Preliminary experiments suggest that this factor is not connected with the queen cells, brood, food or combs. It would therefore appear to be connected with the adult bees in some way.

It seems probable that the production of queen cells by a swarming colony is due to factors similar to those which operate when a colony becomes queenless. This aspect of the problem is also being investigated.

Foraging of Wasps and Bumblebees

Dr. C. G. Butler and Miss E. Tyndale-Biscoe have examined the possibility that the workers of some of the common social wasps are able to communicate to one another within the nest information with respect to the position of particular sources of food. A considerable quantity of data were collected and all indicate that the species of wasps studied were unable to communicate with one another in this way. The data also indicate that carbohydrate forms an important part of the food supply of wasp colonies at all events during the late summer and early autumn, and, for example, that the same wasps will regularly visit a dish of sugar syrup and will give the syrup collected to other members of their colonies.

Mr. J. B. Free has been studying the foraging behaviour of

several species of Bumblebees. He has obtained evidence which suggests that individuals of *Bombus terrestris*, *B. lapidarius* and *B. agrorum* may repeatedly return to forage on the same small area of a crop of red clover. When several nests of *B. agrorum* in which all the individuals were marked were placed in a red clover field, in no case was a worker seen at a greater distance than twenty yards from her nest. It is hoped that further work on the foraging areas of the different species will be possible. It has also been confirmed in experiments with artificial flowers that bumblebees prefer to visit those flowers which contain the most concentrated sugar solutions, as do honeybees. No evidence of communication of information between bumblebees has been obtained.

Nectar Secretion

Dr. Gwenyth Wykes has, with the assistance of Miss E. Carlisle, continued her survey of the nectars of the more important species of flowers visited by honeybees. Qualitative analyses of the sugars occurring in the nectars of about sixty different species have now been made. This investigation has shown that sucrose, glucose, and fructose, sugars which are highly attractive to bees, were present in the nectars of all but one of the species examined, and traces of maltose and two other rarer sugars were also found in certain species.

Since this exploratory work suggested that the relative proportions of the sugars in different nectars varied widely, and since such variations are likely to influence bee visits, a series of quantitative analyses of the sugars occurring in the nectars of some of the major honey-producing crops were made during 1951. It is hoped to extend this work during 1952.

Field observations have indicated that under certain conditions poor crops of fruit and seed may be due to inadequate pollination. This in turn could result either from the absence of sufficient pollinating insects or from shortage of available and attractive nectar in the flowers. Miss M. Ryle has, therefore, been conducting preliminary trials to test the effects of certain commonly used mineral fertilizers on the quantity of sugar secreted by the nectaries of various plants. In all cases the experiments were of factorial design with N, P and K each at two levels. With the kind permission of the Director of East Malling Research Station and the generous assistance of several members of his staff, it was possible to make observations on the nectar production of a set of apple trees which have been receiving differential manurial treatments for many years. Preliminary results suggested that trees receiving phosphate were producing more sugar per flower than those depending only on that which was initially present, but the difference was not significant. However, the observation will be repeated in 1952.

Sand culture experiments were also made using mustard, red clover and buckwheat as test plants and using N, P and K, at two levels. The results are now being analysed.

Physiology

Mr. L. Bailey has, as a part of his programme of work on Nosema disease, studied the physiology of pollen digestion by the honeybee. Pollen, taken as a suspension in honey by the bee, accumulates in

the honey-stomach and is then filtered from its liquid medium to be passed into the ventriculus.

The precise mechanism of the filtration was observed by cutting out a small window over the site of the proventriculus in the abdomen of the anaesthetized bee, allowing the bee to recover and then feeding with a suspension of strained pollen. Observation of the proventriculus showed that it draws a small volume of suspension into its lumen and then expels the fluid back into the honey-stomach, retaining the pollen by means of the posteriorly directed combs of hairs and storing it in four pouches. When a large mass of pollen is collected by the organ, it is expelled posteriorly as a bolus into the ventriculus.

The rate of pollen filtration was determined and significant differences were noted with different suspensions of particles of different sizes and also with different volumes of suspension containing particles of the same size. Particles such as the spores of *Nosema apis* ($8\mu \times 3\mu$) were filtered with complete efficiency. A few similar observations on bumblebees and some solitary bees showed that the former were less efficient than the honey bee in filtering pollen and the latter could not filter pollen at all. These differences were accounted for by the study of the anatomical details of the proventriculi.

The proteolytic activity of the ventriculus of the honeybee was determined by its ability to digest gelatine. Its power of digestion was markedly reduced by the presence of honey even when the honey was adjusted to the same pH as the ventricular contents. This suggests that the filtration mechanisms of the proventriculus assists the digestion of pollen by the ventriculus by the exclusion of honey from the ventriculus until all the pollen has been filtered off. The pollen collects in the posterior half of the ventriculus as a compact mass, having been mixed with the proteolytic enzymes secreted by the ventriculus. Thus the enzymes are neither diluted nor inhibited by an excessive amount of honey.

It seems likely on the grounds given above, that solitary bees have not the same ability to digest pollen as have honeybees and this gives the honeybee two distinct advantages over the solitary bees: (1) Larval honeybees are fed with a prepared protein food from the pharyngeal glands of the adult bee. This ensures a diet more consistent in quality and quantity and more compact in volume than pollen. (2) The adult honeybee stores protein within its own body which may be instrumental in its ability to survive the winter and certainly provides a ready source of food for the larvae in the early part of the year when brood-rearing commences.

The ability of bumblebees to digest pollen is probably intermediate between that of the honeybee and solitary bee but the problem remains to be solved.

The relationships between the mechanics of pollen digestion and other physiological phenomena of the alimentary tract of the honeybee with the course of infection of the ventriculus by *Nosema apis* are now being studied.

Dr. C. G. Butler and Mr. J. Simpson have attempted to correlate the degree of activity of certain glands of the worker honeybee with

her age and occupation. The proteolytic activity of the ventricular glands of different bees were found to be variable in early adult life 5-20 days of age), but consistently low in a few older bees (31 days of age) examined. The ventricular glands of bees feeding young brood were all found to have a greater degree of proteolytic activity than those of foragers. Comparison of this result with the data mentioned above showed that there were some bees as young as six days old which were almost certainly not feeding young brood and were probably foraging. The amount of invertase found in the pharyngeal glands of foraging bees was just significantly greater than that found in bee that were feeding young brood.

Both proteolytic activity and invertase content showed considerable variations in the bees examined.

Bee Breeding, etc.

The maintenance of several distinct strains of bees was continued by the use of instrumental insemination. Work is being continued on the development of syringes which are easier to use and to make.

Experiments have also been carried out on spring stimulation and an article on this subject has been published (13D) ; on the effect of colony density in given areas on the size of the resulting honey yield ; and on various other aspects of practical beekeeping.

INSECTICIDES AND FUNGICIDES DEPARTMENT

By C. Potter

The continued absence of Mr. M. J. Way on secondment to Zanzibar has decreased the amount of biological work carried out in the current year. Dr. A. H. McIntosh returned from the United States of America and Dr. K. A. Lord from the Biochemistry Department, Cambridge, at the beginning of the year, and resumed their programmes of work. Both these members of the department felt they had greatly benefited by their experience.

Mr. Neely Turner, Entomologist, of the Connecticut Agricultural Experiment Station, U.S.A., arrived at the beginning of the year for a stay of six months in exchange for Dr. A. H. McIntosh. Mr. Turner's visit proved very profitable for the department, the members of which were able to benefit from his wide experience. Mr. Turner expressed himself well satisfied with the experience gained from his stay here. Mr. R. W. Kerr, of the Commonwealth Council of Scientific and Industrial Research Organization, Canberra, returned to Australia in October.

In March the annual conference of research workers on insecticides for plant protection was held at Rothamsted, and the work of the department was exhibited and discussed.

The British Council organized a course on Insecticides and Herbicides for visiting research workers, and in June a week's course on Insecticides was given at Rothamsted by members of the department. Seventeen delegates coming from Finland, Sweden, Norway, France, Holland, Belgium, Egypt, Italy and Australia attended the course.

Mr. Burt and Dr. Potter attended the Ninth International Congress of Entomology held in Amsterdam in August.

Dr. Hammerlund, in charge of the Insecticides testing section of Government Plant Pathological Station, Lyngby, Denmark, visited the department and stayed for about six weeks, studying techniques for the assessment of insecticidal action.

The work of the department during the year is set out below :—

Chemical

Physical chemistry

(1) The effect of particle size of suspensions of contact insecticides on their toxicity.

Since his return from the U.S.A. Dr. A. H. McIntosh has continued his work on this subject. In 1950, tests of suspensions by injection into adult *Oncopeltus fasciatus* Dall. had suggested that the relative insecticidal behaviour of different-sized particles of solid poisons depends on their fat solubilities. If the ratio of median lethal dose to solubility in oil is high, small particles seem to be more toxic than large ones. The difference is only in speeds of action, the ultimate toxicities of large and small particles being the same. Differences in speed of action are more easily measured if the

insects are kept cool after treatment. If the ratio of median lethal concentration to solubility in oil is low, the difference in speeds of action between large and small particles may not be noticeable, even with cool insects. All this applies to injection tests.

These ideas are now being applied to the behaviour of suspensions tested for contact action. It is assumed that in contact action, the first step in penetration of the cuticle is solution in the wax layer of the cuticle, whereas in injection tests (*O. fasciatus*) the first step is solution in the fats of the blood stream. The manner in which different-sized particles act, therefore, depends on their physical properties, especially solubility in fats, which may itself depend on particle-size.

With each of about 10 D.D.T. analogues, two suspensions have been made—one of colloidal poison, and one of crystalline particles of about 20-50 μ. These have been tested against *Oryzaephilus surinamensis* L. by the dipping method, the insects being kept cool (11°C) after treatment. If there is a large difference in speeds of action, the difference in toxicity between colloidal and crystalline poison appears to be large if the insects are inspected soon (one day after treatment). The analogues chosen cover a range of fat solubilities: for each analogue the solubility in olive oil at 11°C has been measured.

From the results obtained so far it can be seen that the relation of fat solubility to *difference* in speeds of contact action is not as simple as in injection tests. Other physical properties (speed of flocculation of colloidal poison and speed of solution of poison in wax) are involved. The problem is being investigated further.

(2) Effect of surface active agents on the action of contact insecticides.

Work on this subject has been temporarily suspended while some factors in the techniques of investigation are being studied.

Biochemical

Previous work has shown that esterases other than choline-esterase were inhibited in high dilution by the organo-phosphorus insecticides and might be concerned in the mechanism of toxic action of these compounds. During his stay in the Biochemistry Department at Cambridge, Dr. Lord made some progress in isolating and studying the properties of one of these esterases, but this work was held up when he returned to Rothamsted owing to lack of equipment.

In the interim while the necessary equipment is being obtained, further studies of the activity of extracts from different species of insects were investigated in order to study the distribution of esterases hydrolysing both acetyl choline and other substrates. The relative amounts of these types of activity varies considerably with the species.

Using organo-phosphorus insecticides as inhibitors, it has been found that there were large differences in the amounts of material required to inactivate a given amount of esterase from different species of insect using phenyl acetate as substrate. This would

provide a biochemical basis for specificity. It was further found that pure Parathion [0 : 0-diethyl 0-(p-nitrophenyl) thiophosphate] is not an inhibitor of the " non-specific " esterase from *Tribolium castaneum* Hbst. adults, although it is an effective insecticide against this species. Pure parathion has also been reported as having no inhibitory activity against mammalian choline-esterase.

A start has been made by Dr. Lord and Dr. Potter in comparing the relative toxicity of insects of three analogues of parathion with their capacity to inhibit insect esterase. The analogues were chosen because it had been reported that their mammalian toxicity did not run parallel to their insecticidal activity. The mammalian toxicity based on tests on rats of the three compounds has been reported to be as follows : 0 : 0-diethyl S-(p-nitrophenyl) thiophosphate > 0 : S-diethyl 0-(p-nitrophenyl) thiophosphate > 0 : 0-diethyl 0-(p-nitrophenyl) thiophosphate (parathion). The insecticidal activity based on the contact effect on adult *Tribolium castaneum* Hbst. ranks the materials as follows : 0 : 0-diethyl 0-(p-nitrophenyl) thiophosphate (parathion) > 0 : S-diethyl 0-(p-nitrophenyl) thiophosphate > 0 : 0-diethyl S-(p-nitrophenyl) thiophosphate. The anti-insect esterase activity of the three compounds to an extract from *Tribolium castaneum* Hbst. acting on phenyl acetate as substrate ranked the compound as follows : 0 : S-diethyl 0-(p-nitrophenyl) thiophosphate > 0 : 0-diethyl S-(p-nitrophenyl) thiophosphate > 0 : 0-diethyl 0-(p-nitrophenyl) thiophosphate > (parathion) which in pure form does not inhibit in saturated solution. From this data it would appear that the order of contact insecticidal action of this series of analogous compounds to *Tribolium castaneum* Hbst. is exactly the reverse of their order of toxicity to mammals (rats).

The insecticidal activity could be correlated with capacity to inhibit insect esterase with two of the three compounds, the reason for the inability of pure parathion to inhibit esterase in vitro while it is highly toxic in vivo remains to be explained.

A considerable amount of work of an exploratory nature including experiments on insect dehydrogenases has been carried out by Dr. Lord, but has not so far advanced beyond the preliminary stage.

Relationship between chemical constitution and insecticidal activity

The work on the biological activity of molecules allied to the pyrethrins has been continued by Mr. Elliott, Mr. Needham, and Dr. Potter.

An investigation of the effects on insecticidal activity of altering the structure of the acid parts of pyrethrin-like esters has been carried out. Most of the compounds used were kindly donated by Dr. S. H. Harper of King's College, University of London.

The contact effects were studied by means of a measured drop technique ; three different insect species were used to detect variations in susceptibility and any possible variations in relative toxicity of any two compounds with species.

A summary of the results is set out in Table 1.

TABLE 1. *The effect of variations in the structure of pyrethrin-like esters on their relative contact toxicity*

Alcohol	Acid	Relative toxicity *Phaedon cochleariae*	*Tenebrio molitor*	*Dysdercus fasciatus*
(±)-allylrethronyl	(+)-*trans*-chrysanthemate	100	100	100
,,	(±)-*trans*- ,,	44	48	53
,,	(±)-*cis*- ,,	32	32	25
,,	(—)-*trans*- ,,	4		
(±)-2′-methallylrethronyl	(+)-*trans*- ,,	69		
,,	(±)-*trans*- ,,	28		
,,	(±)-*cis*- ,,	12		
(±)-allylrethronyl	(±)-*trans*-dihydro-chrysanthemate	20		
,,	5-methyl-*n*-hex-2-enoate	<0·1		

(For nomenclature used, see Harper, "Chemistry and Industry," 1949, 636.)

From these results it appears that the (+) *-trans* and (+) *-cis* forms of chrysanthemum monocarboxylic acid form toxic esters, whilst the (—) *-trans* and the (—) *-cis* forms produce relatively non-toxic compounds.

The comparison of (±) -allylrethronyl (±)—trans-dihydro-chrysanthemate with (±) -allylrethronyl 5-methyl-*n*-hex-2-enoate was carried out to find out if the cyclopropane ring were an essential feature of the acid for high pyrethrin-like activity. The acyclic acid for this comparison was prepared by Mr. Elliott in this department. From the fact that the ester from the acyclic acid and (±) -allethrolone was non-toxic to adult *Phaedon cochleariae* when applied as a measured drop at 5 per cent w/v. in acetone as shown in the table, it appears that the cyclopropane ring structure in the acid is necessary for high toxicity.

It is noteworthy that in the tests given above, the relative toxicity of the compounds tested is very nearly the same with all three species of insects, and with a given species of insect, changes in acidic structure have the same relative effect when the alcoholic component has the allyl or the methallyl side chain.

Organic chemistry

Mr. Elliott has continued his chemical work in connection with the study of the relationship between chemical structure and insecticidal activity.

(1) The main subject of work has continued to be the synthesis of ketones related to pyrethrolone, cinerolone and allethrolone (2-*n*-penta-2′ : 4′-dienyl-, 2-*n*-*cis*- but-2′-enyl- and 2-allyl-3 methyl-*cyclo*pent-2-en-4-ol-1-ones respectively). A detailed description of this work will be published shortly and an adequate summary cannot be made here.

(2) In the course of the experiments outlined under (1) above, it has been shown that alkylidene succinic anhydrides absorb in the ultraviolet region at 2350A. (ε max. 10-12,000), whereas the parent alkylidene succinic acids show the expected absorption at ca. 2200A. An examination of the probable causes of this shift in the position of maximum absorption has been made.

(3) Hedenburg and Wachs (J. Amer. Chem. Soc., 1948, **70**, 2216) have shown that 3-alkyl-5(-3 : 4-methylenedioxyphenyl-*cyclo*hex-2-en-1-ones have insecticidal activity themselves to houseflies and also

synergize the action of the pyrethrins. They concluded that the system $-C=CH-C=O$ was essential for insecticidal activity in these compounds. In particular they described 3-hexyl-5-(3 : 4 methylenedioxyphenyl)-*cyclo*hex-2-en-1-one (" piperonyl cyclonene "). It was thought that 2-allyl-3-methyl-5-(3 : 4 methylenedioxyphenyl)-*cyclo*hex-2-en-1-one would be an interesting compound since it would contain the system $CH_3-C=C(CH_2CH=CH_2)-C=O$ which is present in the synthetic insecticide allethrin and it has been suggested (Elliott, Pyrethrum Post, 1951, **2**, No. 3, 18) that the insecticidal activity of the keto esters in the natural pyrethrins and allethrin may to some extent be correlated with the activation of the α-methylene grouping in the keto-alcoholic side chains of these compounds. This compound (λ max. 2,400A., ε max. 11,000 ; 2 : 4-dinitrophenylhydrazone, orange needles m. p. 162° (uncorr.) has therefore been made by variations of the published method. Reports on the insecticidal and synergistic properties of this compound (which is related to piperonyl cyclonene) for the pyrethrins and for allethrin will be made.

(4) Photometric methods employing the ultraviolet absorption of the natural pyrethrins have been advocated by Beckley (Pyrethrum Post, 1949, **1**, No. 3, 5 and 1950, **2**, No. 1, 23) and by Shukis, Cristi and Wachs (Soap and Sanitary Chemicals, 1951, 27, No. 11, 124). It was of interest, therefore, to see whether these substances showed deviations from the Beer-Lambert Law due to fluorescence in the region of absorption (c.f. Brande and Timmons (J. Chem. Soc., 1950, 1019)) and especially to determine whether the effects were appreciable in the range of extinction (optical density) values recommended by these workers. It has been shown that the " α-dl-*trans* " isomer of allethrin (a specimen of which was available by the generosity of Dr. M. S. Schechter ; see Schechter, La Forge, Zimmerli and Thomas, J. Amer. Chem. Soc., 1951, **73**, 3541) does show such deviations in ethanol and in *n*-hexane, but that the relationship optical density *vs.* concentration is linear at and below the maximum optical density readings suggested by Shukis *et al.*

These results and a discussion of the probable effects of any variation in the pyrethrin to cinerin content in various samples of pyrethrum flowers estimated by photometric and the more conventional chemical methods will be published.

Insecticides Derived from Plants

Pyrethrum

The insecticidally active principles of Pyrethrum Flowers have been identified in the past by a study of their products of hydrolysis.

They can be re-sinthesized individually from these products but a purely physical method of separation would be valuable, both as a means of improving methods of analysis and as a source of pure compounds for toxicity tests.

In the course of collaborative work with the Colonial Products Advisory Bureau, Dr. K. A. Lord and Mr. J. Ward, using a chromatographic column of alumina, achieved a complete separation of Pyrethrin and Cinerin I from Pyrethrin and Cinerin II.

A method of carrying out this separation by paper chromatography has been evolved and this provides a useful qualitative test

of the presence of the " Pyrethrins " I and II. Some evidence of a partial separation of the cinerins on the column has also been obtained.

The presence of esters with the monocarboxylic acid and of those with the dicarboxylic acid in the washings was shown by their U.V. absorption and also by chemical methods. This evidence has been supported by bioassay for insecticidal activity.

Heliopsis spp.

Following a report from the United States on the insecticidal effectiveness of an amide called " Scabrin " isolated from the roots of *Heliopsis* spp., and in response to a request from the Colonial Products Advisory Bureau, some work has been started on these plants. Seeds of *Heliopsis scabra* and *H. parvifolia* have been obtained through the good offices of the Colonial Products Advisory Bureau and plants of both these species have been grown successfully in the open air and in the glasshouse. Seeds have been collected for germination tests. Dr. Martin Jacobson of the United States Department of Agriculture Bureau of Entomology and Plant Quarantine kindly sent us a sample of Scabrin and Mr. P. H. Needham carried out some preliminary biological tests using Adults of *Tenebrio molitor* L. (Meal worm), *Phaedon cochleariae* Fab. (Mustard beetle) and *Dysdercus fasciatus* (Cotton stainer). The contact effect of the scabrin in these three species were compared with that of (±)-allylrethronyl (±)-*trans*-chrysanthemate. The relative toxicity ranged from approximately 1/30 with male *Dysdercus fasciatus* to approximately 2/3 with *Tenebrio molitor*. It would appear from this that Scabrin is not likely to be as insecticidally active as the pyrethrins and the pyrethrin-like esters over a range of insect species, but is sufficiently active to justify further investigation, particularly since it would appear that other N-*iso*butylamides have considerable insecticidal activity.

It is proposed therefore to continue to work on this plant insecticide.

Biological

Bioassay techniques

Measured drop technique

In connection with the work on the bioassay of synthetic pyrethrin like esters, a measured drop technique of testing contact insecticides has been developed by Mr. P. H. Needham.

In the first instance this technique was used because comparisons of insecticidal activity can be made with very much smaller samples of poison than with the " Potter Tower " spraying method, and this is an important factor because the samples of some of the synthetic compounds being examined are extremely small.

The apparatus consists of a standard 1 ml. micrometer syringe of the " Agla " pattern with a cannula affixed in the place of the needle. The poisons are applied as solutions in pure solvents. Acetone, ethyl alcohol and olive oil had so far been used with success.

Adults of *Phaedon cochleariae*, *Tenebrio molitor* and *Dysdercus fasciatus* have been used as test subjects and very consistent and

satisfactory results have been obtained. The data have consistently provided non-heterogeneous probit lines which could be repeated. So far it has not appeared to be necessary or desirable to provide any of the arrangements that have been described for removing the drop from the needle.

Injection techniques

Mr. P. H. Needham has continued to work on this subject. It was thought that earlier failures may have been due to the formulation of the poisons and the relatively large volumes injected.

Previously the insecticides, in this case " synthetic pyrethrins", were formulated in a sulphonated lorol/water medium containing 10 per cent acetone. Now by using hot olive oil and an oil soluble emulsifier, aqueous injection media giving satisfactory results have been obtained.

Only *Tenebrio molitor* adults have been used for this work so far, but we hope to increase the range of test subjects in the near future.

Spraying techniques

Dr. Potter and Mr. A. J. Arnold have made an examination of the physical factors affecting the performance of the improved model of the laboratory contact spraying apparatus (the Potter Tower) in use in the department, and this work has been sent in for publication. With distilled water a difference in the environmental temperature of 20°F between 60°F and 80°F produced approximately 10 per cent difference in the deposit of spray droplets and a difference of 20 per cent in the relative humidity of the environment between 60 per cent and 80 per cent produced approximately 5 per cent difference in the deposit. A short investigation of the possible influence of electrostatic effects on the amount of spray deposit indicated that variations in the charge on the droplets did not influence the amount deposited. The deposits remained the same when potentials up to 1·5 kilovolts were applied to the spray target.

During the course of these investigations it was found that the nature of the surface active agent used in the spray greatly affected the charge on the spray droplets. With a solution of anionic wetting agent no charge could be measured while in the presence of two non-ionic materials the charge was greatly increased over that on distilled water. In a given set of conditions a droplet of distilled water of average weight 0·00013 mg. at a potential of 25 volts carries a change of 0·00026 e.s.u. and a droplet of 5 per cent v/v. lissapol N. (non-ionic surface active agent) of average weight 0·000084 mg. at a potential of 49 volts carries a change of 0·00044 e.s.u. By the process of elimination it appears likely that the major factor producing variations in the deposit is variations in the turbulence induced in the tower.

Technique of estimation of contact poisons

Dr. Potter and Miss Christine Hutt have continued their examination of the relative importance of direct contact effects and residual film effects in laboratory insecticidal assay and on the factors influencing these effects. This work is nearing completion.

Synergism between nicotine and the pyrethrins

Mr. Neely Turner had previously found evidence of the occurrence of synergism between nicotine and the pyrethrins when these two insecticides were injected into adult *Oncopeltus fasciatus* Dal.

During his visit he studied the action of these two poisons applied jointly as contact poisons to adult *Tribolium castaneum* Hbst. by means of a dipping technique.

When the two poisons were applied simultaneously no evidence of synergism was found, but when the nicotine was applied first and the pyrethrins subsequently after an interval of three-quarters of an hour there were indications of synergism. A possible reason to explain these facts is the unequal rates of penetration of the two poisons.

This work has been accepted for publication.

The effect of stage of development on insect resistance

Miss Helen Salkeld from Canada has continued her work on the changes in resistance of insect eggs to insecticides that occur during development. The majority of the work has been done on eggs of the tomato moth *Diataraxia oleracae*, and in an attempt to determine the basis of changes in susceptibility during development Miss Salkeld has made a detailed study of the structure and changes that occur during development of the layers composing the egg shell in this species of egg. In order to facilitate this study Dr. V. B. Wigglesworth kindly agreed to her spending a month working under the supervision of Mr. Beament in the Entomology Department at Cambridge. In addition to the eggs of *Diataraxia oleracea* the eggs of *Ephestia kuhniella* and *Dysdercus fasciatus* have been included in the study. The effects of D.D.T., the pyrethrins, allethrin, T.E.P.P., Parathion and the triethanolamine salt of 3·5 dinitro-ortho-cresol have been investigated.

Differences in resistance during development have been found with all three species of eggs, but the nature of the curve for susceptibility differs for each species. It has further been found that there are considerable differences between the different insecticides in the ratio between the dose required to give approximately 100 per cent kill and that required to inhibit the development of the embryo.

Factors affecting the toxicity and permanence of insecticidal deposits on plants

Mr. P. Burt and Mr. J. Ward have continued their studies on the behaviour of D.D.T. deposits on films of plant waxes and have extended their work to include the behaviour of D.D.T. deposits on living plants.

Modifications have been made in the Schechter-Haller method for determining D.D.T. in order to adapt it to the analysis of deposits on leaves. Reliable results may now be obtained on samples containing 15 micrograms of D.D.T.

Previous work had shown that deposits of D.D.T. crystals on glass plates, either plain, or coated with sisal wax, when stored at 45°C showed a loss of approximately 50 per cent in a fortnight, both by biological and chemical estimation. This was presumed to be

due to volatilization. Further experiments were done to obtain some evidence on this point and to find out if similar effects would be obtained with a more typical plant wax. A 10 gm. sample of wax from cabbage plants was prepared, and 0·5μ thick films of this wax were sprayed on glass plates.

Waxed plates sprayed with crystalline D.D.T. suspensions of different concentrations together with unsprayed plates were kept at 45°C in an atmosphere saturated with D.D.T. vapour. No loss of insecticidal activity was found in the high concentrations of D.D.T. after three weeks and at the lower concentrations both the activity and D.D.T. content had increased. The waxed control plates had also become insecticidal. It was shown in a later experiment under the same conditions that the untreated waxed plates could pick up from the atmosphere 0·8 micrograms of D.D.T. per cm^2 in 11 days, which was enough to produce a 1·6 per cent solution in the wax.

Taken as a whole these experiments indicate that at 45°C in the open considerable losses of D.D.T. from a surface may occur due to volatilization in a few days. They further show that D.D.T. can go into solution in plant wax via the vapour phase.

Further experiments showed that the median lethal dose to adult *Tribolium castaneum* of wax films containing D.D.T. absorbed from the vapour phase did not differ greatly from films coated with an equivalent amount of D.D.T. in the form of 50μ needles or from films prepared by spraying a solution of wax and D.D.T. in benzene, although it was clear that the slopes of the probit regression lines of mortality on concentration were different with the different treatments.

The experiments so far have indicated, although the evidence is by no means conclusive, that the D.D.T. absorbed from the vapour phase is evenly distributed in the wax layer. Further experiments are in progress on this subject and on the effect of the physical state of the applied poison on its toxicity.

Preliminary work on leaf surfaces has shown that differences in contact insecticidal activity occur with different species of plants, when the leaves are sprayed to the same deposit density, and there is a much more marked difference between all leaf surfaces so far tested and glass plates, the latter invariably being considerably less toxic. Work is in progress to determine the reasons for these differences.

For the work on leaf surfaces it was necessary to provide a technique for the application of known repeatable doses evenly over the leaf surface. The " Potter Tower " which had been used to coat the plates was not suitable for coating leaves on the living plants. A technique has been worked out giving a coefficient of variation of the deposit of about 5 per cent over a sampling area of 67 sq. cm.

Mechanism of selection of strains of insect resistant to insecticides

Dr. Tattersfield has continued his work on this subject assisted during the year by Mr. R. W. Kerr from Australia and Miss Jill Kerridge.

Continuous selection by treatment at three-weekly intervals over the period of a year, of adults of a wild stock of *Drosophila melanogaster* with D.D.T. was carried out in 1950. The effect of

selection was tested at two levels of survival, approximately 90 per cent kill and approximately 60 per cent kill. Considerable fluctuations occurred throughout the period of selection, but it was finally estimated that at the end of the year the stock selected from the high level kill was two to three times as resistant as the untreated stock. Little if any change in resistance had occurred in the stock selected from the lower level kill. A comparison of the respiration rates of resistant adults with those of normal adults indicated that the resistant individuals had a higher rate. Further work is being done on this point.

Various possible sources of the fluctuations in susceptibility that occurred during the course of this work were investigated including (1) carbon dioxide susceptibility and (2) temperature effects. A series of experiments showed that at least a considerable proportion of the variation was due to the presence in the stock of a strain susceptible to CO_2, the CO_2 susceptibility having a considerable negative temperature coefficient. Ph. L'Héritier discovered the phenomenon of CO_2 susceptibility in a strain of *Drosophila* between 1938 and 1940 and some of his stock was sent to Rothamsted in 1941. It seems probable that this strain became incorporated in the wild stock used for these experiments.

The CO_2 susceptibility has been ascribed to a plasmagene or a virus that can be transmitted to the progeny more potently through the female than the male.

Work is in progress to ascertain whether selection for CO_2 resistance will lead to D.D.T. resistance and whether insects selected for D.D.T. resistance using nitrogen for anæsthesia, will be CO_2 resistant.

Mr. Kerr has carried out investigations on the techniques of rearing and handling *Drosophila* for the specific purpose of investigating the factors affecting their susceptibility to insecticides, and his work has resulted in considerable improvements and the speeding up of the spraying technique. He further devised a micro-technique for applying very small drops of insecticide quantitatively to individual insects.

Using the micro drop technique he has shown that the susceptibility to D.D.T. of adult *Drosophila melanogaster* varies with age and has determined the age of maximum resistance.

Other factors influencing resistance that have been studied, include the effect of the age of the parent on the susceptibility of the progeny and the effect of the temperature of rearing upon susceptibility.

The work as a whole has been seriously hampered by lack of facilities for providing constant temperature and humidity.

Insect rearing

Seventeen species of plant feeding insects and 12 species of stored products insect have been reared during the course of the year. *Phaedon cochleariae* the mustard beetle has proved to be a useful test insect and Miss P. Smith has continued her work on the technique of rearing this insect and on the environmental factors affecting its diapause.

The methods of rearing aphids in the department have been unsatisfactory, since, in addition to difficulties due to the attacks

of parasites and predators, the populations fluctuated greatly for reasons that are not yet understood. Mrs. J. Kenten has started to work on improved methods of rearing and to study the underlying causes of fluctuations in the reproduction rate and in the proportions of the different morphological forms in the population.

Toxicity of plant protective chemicals to bees

Mr. Glynne-Jones has continued to work on this subject at Seale-Hayne Agricultural College in collaboration with this department.

The following laboratory estimations have been made of the toxicity of three of the newer insecticides.

Approximate L.D. 50 *in* 24 *hours*

	Stomach poison	Contact poison	
	mg./bee	conc : w/v. %	deposit/sq.cm.mg.
Aldrin	0·00027	0·0065	0·00063
Chlordane	0·0012	0·06	0·0059
Toxaphene	0·04	0·5	0·048

The low toxicity of toxaphene is noteworthy.

In view of the importance of dust formulations in plant protection some work has been started on the action of dusts on bees.

A detailed study of the external morphology of the bee as affecting the entrance of dusts has been made.

Serial sections through the abdomen of dusted bees have shown that hairs within the vestibule are efficient filters of particles greater than 5μ in diameter and it was never possible to find dust particles in the tracheae.

It has been shown that a number of different materials in the form of dusts can increase water loss by the bee when they are brought in contact with the cuticle. This occurs in both living and dead bees. Alumina-aluminium oxide (Almicide) was the most effective, but others such as activated charcoal and calcium carbonate had some effect, perhaps due to their adsorptive properties.

The possible function of the dense covering of hairs in protecting bees from dusts is also being investigated.

Further consideration has been given to the development of a technique for the evaluation of repellent materials and the effects of a series of chemicals allied to phenol have been examined. The results have so far failed to reveal any predictable relationship between chemical constitution and repellancy.

Field Work

Control of wireworms

A preliminary experiment to obtain some data on the possible use of Aldrin and Chlordane for wireworm control was carried out in 1950-51 on the site of the previous experiments of 1947-50, using the control and seed-dressed plots of the earlier experiment. A B.H.C. combine-drilled treatment was included as a standard.

A dust contining 2½ per cent Aldrin was combine-drilled at 190 lb. per acre (4·75 lb. Aldrin per acre). A dust containing 5 per cent Chlordane was combine-drilled at 100 lb. per acre (5 lb. Chlordane per acre), and a dust containing 3·5 per cent technical B.H.C. (technical B.H.C. containing 12-14 per cent gamma isomer) combine-drilled at 75 lb. per acre (2·62 lb. technical B.H.C. per acre). The

figures for grain yields in cwt. per acre from the treated plots were as follows :—

Experiment 1 : Untreated $19{\cdot}8 \pm 0{\cdot}32$, Aldrin $26{\cdot}2 \pm 0{\cdot}45$ B.H.C. $25{\cdot}7 \pm 0{\cdot}45$.

Experiment 2 : Untreated $14{\cdot}7 \pm 0{\cdot}84$, Chlordane $18{\cdot}2 \pm 1{\cdot}18$, B.H.C. $20{\cdot}1 \pm 1{\cdot}18$.

From these figures it appears that both the Aldrin and Chlordane treatments give an increase in yield not significantly different from the B.H.C. treatment and that all the treated plots gave yields significantly better than the untreated plots. In view of these results a more detailed experiment on a fresh site has been started in collaboration with the Entomology Department. In these experiments it is proposed to study and compare the direct and residual effects of Aldrin, Chlordane, D.D.T., and B.H.C.

Effect of insecticides on the population of Aphis fabae scop. (bean aphis) on field beans and on the resulting crop

Experiments reported in 1950 had shown that the population of *Aphis fabae* on field beans could be markedly reduced by a single application of Parathion, H.E.T.P. or Nicotine ; plots treated with D.D.T. subsequently had a higher population than the controls. In the current year a similar experiment was carried out using Parathion (0·02 per cent), Nicotine (0·1 per cent), Isopestox (0·05 per cent), (proprietary material containing Bis (monoisopropylamino) fluorophosphine oxide). Pyrethrum (0·05 per cent total pyrethrins), allethrin (0·05 per cent) and D.D.T. (0·1 per cent). Spring-sown beans were sprayed on 3rd July very soon after infestation was first recorded, at the rate of approximately 150-166 gall. per acre. Records were kept of the changes in the population of both the aphids and their predators and parasites throughout the growing season. All the treatments reduced the aphid population directly after application, and this reduction was maintained to a greater or lesser degree until harvest time. The rapid build-up of population that occurred in the D.D.T. treated plots in 1950 did not occur in 1951. The reason for this difference in effect is not known, but it may be due to a difference in the formulation of the D.D.T. or to differences in the effects on the parasites and predators in the two seasons.

The yield of seed was greatly increased with the more effective treatments. The following figures show the yields in pounds from the differently treated plots ; for each treatment the yield is from four replicate plots each of seven rows 20 in. apart and 10 yds. long : Isopestox 63·5 lbs., Parathion 62·0 lbs., Pyrethrum 59·0 lbs., D.D.T. 56·5 lbs., Nicotine 46·0 lbs., Allethrin 35·75 lbs., Untreated 23·5 lbs.

In view of the considerable increase in yield obtained by the use of insecticides these experiments are being continued.

Control of virus spread by the use of insecticides

These experiments have been carried out in collaboration with the Plant Pathology Department.

Potatoes

Following the indications of a small-scale experiment in 1949 that spread of leaf roll virus could be reduced with insecticides, a further small-scale trial was carried out in 1950 using Parathion (0·125 per cent v/v. technical), Toxaphene (0·05 per cent v/v. technical), Schradan (0·125 per cent v/v. technical), Dieldrin (0·08 per cent w/v. technical) and D.D.T. (0·2 per cent w/v.). Treatments were given on May 23rd, June 2nd, June 6th, June 20th, June 27th, July 12th, July 31st. The figures for the spread of Virus Y which became available in 1951 were: Control × 31, Parathion × 19, Toxaphene × 19, Schradan × 22, Dieldrin × 26, D.D.T. × 37. There was little spread of leaf roll virus in any plot.

Aphid counts in 1950 had shown a reduction in population in all the treated plots but there appeared to be no necessary correlation with the degree of reduction of population and the degree of reduction of virus spread. D.D.T. appeared to reduce the population on the plants to a low level although it is not known whether it had a toxic or repellent effect; the high degree of spread with this insecticide may have been due to its causing increased movement of the population within the sprayed area.

During 1951 a large scale experiment has been carried out on the farm the results of which will not be available until 1952.

Brassicas

A small plot trial on the effect of insecticides on the spread of cauliflower mosaic virus was carried out in 1951 using D.D.T. (0·1 per cent w/v.), Parathion (0·057 per cent) and Isopestox (0·1 per cent) applied to Roscoff Broccoli sown June 20th, 1951. The plants were sprayed at weekly intervals from July 3rd to August 7th. The first spraying was given when the first leaves appeared. No detailed figures for aphids present on the plants were obtained, but very few were present at any time.

The following figures for percentage infections of plants suitable for planting out from the treated plots were obtained: Control 16·9, Parathion 9·8, Isopestox 13·6, D.D.T. 12·3. The reduction in spread caused by the parathion is significant at 10 per cent.

It is proposed to continue this investigation.

FIELD EXPERIMENTS

The following members of the staff, who constitute the Field Plots Committee, are responsible for planning and carrying out the programme of field experiments: E. M. Crowther (Chairman), H. V. Garner (Secretary), H. H. Mann, J. R. Moffatt, D. J. Watson and F. Yates.

The number of plots handled by the Field Staff at Rothamsted and Woburn were :—

	Grain	Roots	Hay	Grazing	Total
Classical					
Rothamsted	131	72	47	—	250
Woburn	24	—	—	—	24
Long-period experiments					
Rothamsted	311	264	228	96	899
Woburn	133	314	55	12	514
Annual experiments					
Rothamsted	289	361	108	—	758
Woburn	—	—	—	—	—
Grand total	888	1,011	438	108	2,445

Note. Grain includes cereals, beans, peas, linseed. Roots include potatoes, sugar beet, mangolds, cabbage, broccoli, kale, leeks, red beet. Hay includes meadow and seeds hay, lucerne, cut grass.

The season 1951 was on the whole a difficult one from the point of view of the field experiments. The autumn of 1950 was exceedingly wet and drilling of winter cereals was so delayed that the usual experiment testing the effect of various manurial, spraying and cultivation treatments on the Eyespot disease of wheat could not be drilled at all and was postponed till next year. On Sawyers I the usual wheat experiment testing dung residues after the previous potato crop had to be drilled in so wet a seed-bed that although a fair crop was produced it was not sufficiently uniform for experimental purposes, and no yields were taken.

The wet weather continued in spring, the first four months of the year exceeding the average rainfall by no less than 6·4 in., with the result that drilling spring corn did not commence till the middle of April. After this long period of leaching, winter corn showed very pronounced signs of nitrogen shortage in spring. Plot 15 on Broadbalk, for example, which receives the whole of its nitrogen in the autumn was strikingly yellow and poor-looking compared with neighbouring plots whose nitrogen was spring applied.

June and July gave the only summer weather of the year, rainfall was light in both months and growth was rapid. In this dry spell the soil became dry enough at Woburn to benefit from irrigation, and the new rotation experiment showed big yield increases due to artificial watering in early potatoes, sugar beet, grass and even in barley.

During the dry spell rooks and jackdaws attacked potatoes at Rothamsted, particularly on Highfield, removing many of the seed tubers from the ridges. Certain of the experimental plots were seriously thinned in this way and yields had to be adjusted for plant number. At this period also birds did so much damage to the broccoli

experiment testing the spread of cauliflower mosaic virus on Highfield that it had to be abandoned. Showery weather set in again in August and lasted through a difficult and protracted harvest. There was some lodging in barley, particularly on the ley arable rotation on Highfield. In this experiment birds attacked the lodged plots to such an extent that no yields were taken. Potato harvest in October was carried out under very good conditions, but the wet weather set in again in November and root lifting and the completion of wheat sowing was delayed.

The Classical Experiments

The classical experiments were continued as usual. In March, Broadbalk wheat which was sown on October 25th looked as well as any on the farm, though the lower end by the drain was very wet and noticeably inferior to the top end. The first-year effect of the bare fallow on Section III was much less noticeable than usual, particularly in the early part of the season, though it stood out better before harvest. Autumn nitrogen either as farmyard manure on plot 2 or sulphate ammonia on plot 15 had very little visible effect on the crop in spring. The dung was more beneficial later in the season, but plot 15 was always exceptionally poor. With the exception of parts of plots 8 and 16 where large dressings of nitrogenous fertilizer are given, there was little lodging. Very thorough pulling of wild oats (*Avena ludoviciana*) in mid-July greatly improved the appearance of the plots for demonstration purposes.

The permanent barley experiment on Hoosfield was in its 100th year, but owing to bare fallows in 1912, 1933 and 1943, only in its 97th crop. It was drilled unusually late on account of the wet spring and was consequently very short in the straw at harvest. Annual weeds were well controlled by spraying with D.N.O.C. (di-nitro-ortho-cresol) but wild oats (*Avena fatua*) which also started into growth unusually late in the season were much in evidence before harvest. Some hand-pulling was carried out but the plots could not be completely cleared.

The barley on the Exhaustion Land sown on March 16th and receiving 2½ cwt. of sulphate of ammonia per acre showed the usual effects of the former phosphatic and dung treatments. In the seedling stage the benefit from phosphatic residues was conspicuous, in mid-season it was not so striking as in recent years, but later in the season the effect was once more apparent. Each of the ten plots was harvested in two sections in 1951 to provide a check on soil variation within plots.

Barnfield mangolds were rather late drilled, but the plants made a good start ; nevertheless the crop was below average in growth especially on the plots receiving dung without inorganic nitrogen and those with complete artificials without dung. The field was very weedy. The sugar beet was a full plant on all plots but the yield of roots was smaller than usual. The Park Grass plots were very late to start growth in spring, but the crop was well up to average at cutting time. A very good second cut was obtained in early October. Wheat on Agdell was a nice-looking crop, but rather small in the ear.

Long Period Rotation Experiments

These experiments were maintained as usual and in general they call for no special comment in 1951. Some important changes in design were made and these are briefly recorded below.

Market garden experiment, Woburn

This experiment was begun in 1942 to test the effects of repeated dressings of bulky organic manures for building up an ordinary farm soil into a state of fertility suitable for market garden cropping.

The results of the first eight years gave useful information as to the effect of organic manures on peas, leeks, beetroot, and cabbage, but there was no certain evidence of the build-up of soil fertility under repeated applications of these manures. In view of the small number of long-term experiments on vegetable crops and the interest in the action of organic manures it was decided that the experiment should be continued, but in a modified form. The original scheme was to grow two crops every year.

1st year : Green peas followed by leeks.

2nd year : Globe beet followed by winter cabbage.

It was found that in most seasons beet and cabbage could not be left long enough to make full growth if the next crop was to be sown at the proper time ; consequently yields were often poor. Under these circumstances the system of cropping was altered in 1951 ; the pea crop was omitted, and spring cabbage was substituted for winter cabbage, giving three crops in two years. The total amount of organic manures was unchanged, each crop now receiving 10 or 20 tons of organic manures per acre, i.e., 30 or 60 tons for the 2-year rotation.

Irrigation experiments, Woburn

From 1947 onwards five field experiments on the irrigation of sugar beet were carried out at Milford, Surrey and Kesgrave, near Ipswich, under the Committee of Sugar Beet Education and Research.* In 1950 these outside centres were terminated and the work was put on a wider basis under the Agricultural Research Council and transferred to Woburn where a permanent installation for overhead irrigation has been set up. The water is derived from the private supply serving the Duke of Bedford's estate, but since the pressure and flow was inadequate for the full needs of the experiment, a storage tank and pumping engine was provided. At the outset three acres on Butt Close field have been laid out for watering, and it is hoped to extend the experiments to a further three acres later. The cropping at present comprises three series of plots one in each crop of a 3-course rotation :—

1st year : Early potatoes followed by winter cabbage.

2nd year : Sugar beet.

3rd year : Barley.

A fourth series of plots has been put down with a long ley for repeated cuttings as for dried grass over a period of years.

* The results have been published annually in the Rothamsted Report.

Every crop tests four irrigation treatments at single and double rates of nitrogenous manuring in three fold replication. Adequate basal dressings of phosphate, potash and lime are applied. In the first year, 1951, the yield of early potatoes was more than doubled by irrigation, there was an increase of about 60 per cent in the yield of cut grass, and 20 per cent in barley grain. The irrigation work is conducted by Dr. Penman and reported by the Physics Department.

Ley arable experiments

In the autumn of 1951 the experiments on Highfield and Fosters completed their third preliminary year. Three-year stands of lucerne, cut grass, and grazed ley were ready for ploughing up for test crop wheat on four blocks, while four had completed a sequence of three test crops and were due to come into treatment crops in spring 1952.

Highfield. Wheat was a good clean standing crop which produced 32 cwt. grain per acre. The effect of the double dressing of nitrogen was visible in the colour but had very little effect on the grain and straw weights. Potatoes looked rather poor but gave a mean yield of 10 tons per acre ; they were badly robbed by birds, and had many blighted tubers. Isolated tubers affected with violet root rot were found at lifting time. Barley was excellent but lodged early in the season, and was subsequently so damaged by birds that no yields were taken.

Owing to the late wet spring the growth of grass was much delayed. The plots were fit to graze about the middle of May but at this time the pressure of work on other experiments was so great that, to gain time, all the second and third year plots that were due to be grazed were cut on May 31st : a month later grazing started on all the appropriate treatments. The modified grazing technique whereby the sheep had one fresh enclosure every 24 hours, instead of being in a large enclosure for several days, was closely followed and resulted in better utilization of the herbage and larger liveweight gains. The sheep were on the plots for from five to seven grazing cycles during the season and the team varied from five to three animals according to the amount of grass available. The third year permanent and reseeded grass plots laid up for hay were cut at the beginning of July ; the plots of old grass were thin, patchy and full of buttercups, the newly reseeded ones were more even and less weedy. The lucerne plots in their second and third year produced three useful cuts of green stuff but showed symptoms of potash starvation although the crop received 1½ cwt. high grade muriate of potash per acre spread over the three years. In the late summer the second and third year lucerne was noticed to be wilting and dying off in patches ; the agent responsible was found to be violet root rot (*Rhizoctonia crocorum*). The extent of the attack was very variable between replicates ranging from nothing up to 13 per cent plants affected. The first year lucerne showed stunted and wilted patches which were probably due to the same cause but this remains to be confirmed. All cut grass plots, including the first year, gave 4 cuts of herbage ; the first cut was taken on June 5th on the established plots but not until July 9th on the first year plots.

Fosters. The test crop wheat on this field was tall, stood well and yielded 28 cwt. at the lower level of nitrogen. The higher level of nitrogenous manuring gave an extra 4 cwt. grain per acre and 8·6 cwt. straw. Barley also was a thick crop and gave 3 cwt. of extra grain for nitrogen and a further 2 cwt. for dung residues ; it tended to lodge where the residues of dung from the previous potato crop coincided with the higher level of nitrogen. The potato crop was much more uniform than on Highfield but yielded rather less. It gave a response of 1·4 tons of potatoes for dung, but little for the higher level of nitrogen. The one year ley, spring sown in 1951 in the open ground, was full of arable weeds and very poor ; it was not weighed. Grass in this exposed field was a week later to start into growth than Highfield. As on Highfield, the reseeded grass and three year leys due to be grazed were first cut on June 6th, and grazing started a month later. There were from 4-6 circuits, with teams of from 2-5 sheep according to the herbage. Lucerne and cut grass gave the same number of cuts as on Highfield, except that the first year cut grass on Fosters was very weedy and poor and gave only one cut taken on October 5th in contrast to four cuts on Highfield. The yields of dry matter from the various grass and legume crops in 1951 are given in the following table.

Yield of herbage crops, Highfield and Fosters, 1951

Mean of both levels of nitrogen

Dry matter : cwt. per acre

	Old grass		Reseeded grass		3 year ley	Reseeded and ley	Grass	Lucerne
	Hay.	Grazed	Hay.	Grazed	Grazed	Grazed	Cut	Cut
Highfield								
Blocks : 1st year	—	52·2	—	—	—	41·7	42·5	33·3
2nd year	—	54·2	—	—	—	57·9	66·6	72·6
3rd year	47·2	23·4*	49·9	18·2*	67·0	—	73·0	73·3
Fosters :								
Blocks : 1st year	—	—	—	—	—	24·4	16·6	13·0
2nd year	—	—	—	—	—	63·6	71·4	84·2
3rd year	—	—	47·4	25·1	64·6	—	67·5	88·8

Note. The figures given for the dry matter production on the grazed plots is derived from the sample cuts taken at every grazing before the sheep were admitted. In the special circumstances of 1951 these figures include the contribution of the preliminary cut taken on all the second and third year grazing plots on May 31st on Highfield and June 6th on Fosters. These cuts account for approximately half of the dry matter figure shown, the remainder being the dry matter in the grazing.

* Aftermath grazing.

All grazing was very productive in 1951, more so than in 1950 which was also favourable for grass. The third year grazing on the leys yielded over 3 tons of dry matter per acre, and this was exceeded by the hay plus aftermath grazing on permanent and reseeded grass on both fields. Cut grass also gave over 3 tons of dry matter in the first and second years, and on Highfield over 2 tons of dry matter in the first. Except in the seeding year, lucerne was more productive than any form of grass of the same age ; the highest yield of dry matter was 88·8 cwt. per acre in the third year on Fosters. This result was observed in a more striking degree in 1950.

In these experiments a double dose of nitrogenous fertilizer is compared with a single dose. This season the effect of the extra nitrogen was in general quite small, the only appreciable response being in aftermath grazing and third year cut grass, in both these crops the increase being about 12 per cent.

Short Period and Annual Experiments

Several of the short period and annual experiments were carried out on behalf of various departments who will themselves report the results. They were :—

(1) Fertilizer placement experiments; winter beans (two experiments) and spring beans—West Barnfield I; potatoes —Great Harpenden I; kale—Highfield IV; lucerne—Long Hoos; old grass—Highfield IX; lucerne and cocksfoot ley—Fosters Corner; Dr. G. W. Cooke, Chemistry Department.

(2) Eyespot of wheat: rotations designed to test the effectiveness of various crop sequences in freeing the land from eyespot (*Cercosporella herpotrichoides*) were continued in Little Knott field. On the north side, the last year of a 3-course rotation showed the effect of 16 different cropping sequences on wheat as a test crop. On the south side, 32 different cropping sequences were being built up for test in wheat in 1953: Dr. M. D. Glynne, Plant Pathology Department.

(3) Effect of nitrogen, phosphate and potash on the incidence of powdery mildew in wheat—Sawyers III: Dr. F. T. Last, Plant Pathology Department.

(4) Effect of insecticidal treatment on virus spread in potatoes—Great Harpenden I. Repeated sprayings during the season with five insecticides: Dr. C. Potter, Insecticides and Fungicides Department, and Dr. L. Broadbent, Plant Pathology Department.

(5) Spread of two viruses in potatoes—Great Harpenden I: Dr. L. Broadbent, Plant Pathology Department.

(6) Spread of Cabbage Black Ringspot virus in cabbage—Highfield IV: Dr. L. Broadbent, Plant Pathology Department.

(7) The effect of time of sowing and singling on virus spread in sugar beet—Long Hoos: Mr. J. W. Blencowe, Plant Pathology Department.

(8) Wireworm experiments on wheat—Little Hoos:
   (*a*) test of chlordane and gammexane combine-drilled with the seed, and residuals of fumigants applied at heavy rates for the wheat of 1948;
   (*b*) test of aldrin and gammexane combine-drilled with the seed, and residuals of dressing of fumigants applied for the wheat of 1948:
   Dr. C. Potter, Insecticides and Fungicides Department.

Application of dung for potatoes

An experiment testing methods and rates of application of dung to potatoes was repeated for the third season in 1951. Yields were only 3·78 tons in the absence of dung; the first 5 tons of dung gave a large increase of 1·73 tons, two further increments of dung each

of 5 tons per acre gave successive increments of 0·69 and 0·61 respectively, showing the falling off at the higher levels noted in the previous years. Sulphate of ammonia gave bigger yields in the presence than in the absence of dung, a result consistent with the large positive interaction observed this season between nitrogen and potash. Dung reduced the response to superphosphate and greatly reduced the response to potash, so much so that in the presence of 15 tons of dung, potash was practically ineffective. In 1951 dung applied in the ridges gave a bigger increase than an equal weight of dung ploughed in in winter or in spring ; this was particularly striking at the low rate of application of 5 tons per acre where the advantage for ridge application was 1·27 tons per acre.

Method of planting potatoes

The study of dropper planting of potatoes begun in 1949 was continued. For mechanical planting the fertilizer was broadcast on the flat, the ridges were then drawn and the seed was placed in the ridges by dropper. The tubers were planted as deep as possible on one set of plots and at the minimum depth to prevent loss through frost and birds on others. The results were :—

Total tubers : tons per acre

Compound Fertilizer cwt. per acre	Hand-planting ordinary method	Machine-planting Deep ±0·443	Shallow	Mean ±0·256
0	3·44	4·73	6·03	4·73
7½	4·67	7·73	7·54	6·65
15	6·59	7·21	8·72	7·51
Mean ±0·256 ...	4·90	6·56	7·43	6·30

The crop was a light one, but it was much improved by fertilizers. The method of planting had a considerable effect on the yield ; even in the absence of fertilizer the machine-planted plots yielded nearly 2 tons more potatoes than the hand-planted ones. During the growing season it was noticed that the plant numbers on the various treatments differed considerably, in spite of the fact that almost equal numbers of tubers per plot had been planted by hand and by machine. Plant counts showed that the mean of all hand-planted plots had 9,900 established plants per acre while the machine-planted plots carried 11,850, an increase of 19 per cent. The mean weight of tubers per plant was also about 19 per cent higher on the machine-planted than on the hand-planted plots ; hence the average improvement in yield due to machine-planting was 42 per cent or nearly 2·1 tons per acre. In this season shallow planting gave significantly more potatoes than deep planting. Fertilizer responses were good generally, but were at least as high on the hand-planted plots as on the others. These experiments will be continued and enlarged to separate the effects of methods of planting from effects due to the location of fertilizer. The loss of plants which has been noted in these experiments when potatoes have been planted in ridges, in certain seasons, needs further examination.

Late nitrogenous top dressings for cereals

In 1950 field experiments were begun to study the effects of late top dressings of "Nitrochalk", applied when the plants were coming into ear, on the yield and the crude protein content of grain and straw. The first year's results showed that in the conditions encountered in 1950 there was no increase in yield of grain or straw due to late nitrogen, but for each of the crops the heavier dressings of "Nitrochalk" gave an extra hundredweight of crude protein per acre in the total produce. The experiments were continued on a larger scale in 1951. The crops were: wheat (Nord Desprez), barley (Plumage Archer), and spring oats (Sun II). The wheat, which was sown early in the autumn of 1950, had a good start, and on May 25th, 1951, the whole piece received a top dressing of $2\frac{1}{4}$ cwt. of sulphate of ammonia per acre. Owing to the wet spring the barley was not drilled till May 2nd, 1951, and received $1\frac{3}{4}$ cwt. of sulphate of ammonia on June 1st. The oats were drilled on April 19th and received a basal dressing of $1\frac{3}{8}$ cwt. sulphate of ammonia on June 4th. Even the basal dressings were applied rather late in the season this year. The wheat and oats received the experimental top dressings of "Nitrochalk" on July 5th, about a week later than in the previous year. The barley was top-dressed on July 11th, about a fortnight later than in 1950.

The wheat was an excellent crop yielding nearly 37 cwt. of grain per acre without late nitrogen. It was all standing and showed no visible effects from the late nitrogen dressings. The barley was also a fine crop of 33 cwt., but was all lodged, the plots receiving the 3 cwt. dressing of "Nitrochalk" were more flat than the rest and later to ripen. The oat crop was thin, very short in the straw and late to ripen. It yielded 18 cwt. grain and an equal weight of straw, only about half the grain and one-third the straw of the year before. There was no lodging, but the straw was slightly taller and greener where the heavy rate of late top dressing had been applied.

July 1951 was, on the whole, very dry and the few light showers that occurred after top dressing were probably insufficient to carry the fertilizer into the soil. The first useful rain was a fall of 0·65 in. at the end of the month and there was plenty of moisture throughout August. Thus the late dressings were probably less favoured by the weather than in 1950 when there were repeated heavy rains soon after application. The experiments of 1951 were considerably more accurate than those of the previous year, and the effect of 3 cwt. of "Nitrochalk" on yield, though small, was statistically significant for both grain and straw in oats, and for straw in barley. Barley grain weighed in its natural condition was also significantly increased by late nitrogen, but this was largely due to the higher moisture content of the top dressed plots, and the effect was not significant in the dry matter.

The following table gives the yield of grain and straw, the percentage of nitrogen in the dry matter, the increase in crude protein, and the uptake of nitrogen.

Late nitrogenous top dressings, 1951

"Nitrochalk" cwt. per acre	Wheat Grain	Wheat Straw	Barley Grain*	Barley Straw*	Oats Grain	Oats Straw*
			Yield, cwt. per acre			
0	36·7	42·8	31·7	24·5	17·7	12·8
1·5	35·9	44·0	32·4	24·8	18·4	13·9
3	36·4	42·0	33·3	27·4	18·7	14·8
S.E. ± ...	0·56	0·71	0·82	0·76	0·29	0·38
			Mean dry matter, per cent			
	82·4	80·8	80·8	61·5	79·2	58·0
			Nitrogen per cent of dry matter			
0	1·87	0·59	1·87	0·78	2·24	0·69
1·5	1·90	0·65	2·05	0·86	2·39	0·85
3	1·93	0·64	2·16	0·94	2·49	1·02
			Increase in crude protein, cwt. per acre			
1·5	−0·02	0·17	0·45	0·14	0·20	0·19
3	0·09	0·08	0·80	0·42	0·31	0·39
			Percentage uptake of added nitrogen			
1·5	−1	12	30	10	14	13
3	3	3	27	14	11	14

On barley the results of the application of late nitrogen were very similar to those observed in 1950. The higher level of "Nitrochalk" increased the percentage of nitrogen in both grain and straw to give an extra 1·2 cwt. of crude protein per acre of which two-thirds was in the grain. The recovery of nitrogen was about 40 per cent at both levels of manuring. Wheat, already a very heavy crop, was little changed by late top dressing in 1951, although the effects on grain and straw were in the usual direction. The total gain in crude protein from the double dressing was 0·17 cwt. per acre, with an uptake of nitrogen of only 6 per cent. The oats were very poor both in grain and straw and the basal nitrogenous dressing was not applied till June 4th; in spite of this the experimental dressing of "Nitrochalk" produced a noticeable but not spectacular improvement in the yield and composition of the crop. Crude protein was increased by 0·3 cwt. in both grain and straw, the total gain being 0·70 cwt. with a utilization of nitrogen of nearly 27 per cent at both levels.

The experiments show that in the not very favourable circumstances of midsummer 1951 late nitrogenous top dressings were effective on barley, and to a lesser extent on oats, but had little effect on a very heavy crop of wheat.

An eighteen-year experiment on ploughing-in straw and compost

During the last 20 years several long-term field experiments have been started at Rothamsted and Woburn to assess the effects of alternative methods of adding organic matter to soils. Leys, green-manures, farmyard manure, composts and straw have been tested in experiments continued long enough to indicate progressive changes in soil fertility as shown by the yields of arable crops following the contrasted treatments.

One of the Rothamsted experiments, which completed its eighteenth test season in 1951, is reviewed below. Its purpose was to

* Yield corrected to 85 per cent dry matter.

test the value of straw ploughed into the land in autumn with fertilizers applied either in the following spring or equally divided between autumn and spring. The two sets of plots with straw were compared with plots without straw and also with other plots receiving straw compost prepared from the same amount of straw and NP fertilizers, the potassium fertilizer being ploughed in with the straw compost.

The above straw and fertilizer treatments were applied to appropriate plots in alternate years in order to have the opportunity of comparing their immediate and residual effects. The experiment consisted of three blocks of land cropped each year with barley, sugar beet and potatoes, respectively, the crops rotating in this order. Each block had 24 plots giving three-fold replication for the four treatments applied in alternate years. (In the early stages of the experiments there were additional factorial tests on two winter green manure crops, but these grew poorly and were soon abandoned).

In addition to the test treatments given in alternate years each plot of sugar beet and potatoes received additional fertilizers as a basal dressing.

The rates of fertilizer dressings and the experimental treatments are summarized below :—

Experimental treatments

In alternate years fertilizers (F) alone with 53·3 cwt. straw per acre or with compost derived from this amount of straw, were applied at the following times :—

	Autumn	Spring
F ...	none	NPK
Ss ...	straw	NPK
Sw ...	straw + ½ (NPK)	½ (NPK)
C ...	straw + NP (as compost) + K ploughed in	none

Additional basal dressings for all plots

	Cwt. per acre		
	N	P_2O_5	K_2O
Barley ...	none	none	none
Sugar beet ...	0·2	0·2	0·25
Potatoes ...	0·4	0·4	0·5

Crop rotation and fertilizer applications
(including basal dressings)

		Cwt. per acre		
	Treatment	N	P_2O_5	K_2O
Barley	fertilizers	0·4	0·4	0·50
Sugar beet	residues	0·2	0·2	0·25
Potatoes	fertilizers	0·8	0·8	1·00
Barley	residues	none	none	none
Sugar beet	fertilizers	0·6	0·6	0·75
Potatoes	residues	0·4	0·4	0·50

Allowing for the nutrients in straw and the losses in composting, the combined dressings in the experimental treatments supplied, over and above the basal dressings, approximately :—

	Cwt. per acre		
	N	P_2O_5	K_2O
F	0·4	0·4	0·5
Ss	0·7	0·5	1·1
Sw	0·7	0·5	1·1
C	0·5	0·3	0·8

A rotation with two root crops in three years was chosen to intensify the loss of organic matter by cultivation. The straw was applied at heavy rates (53 cwt. wheat straw per acre in alternate years) in order to magnify any beneficial effects by improving soil structure, microbiological activity, soil organic matter content or the supply of certain nutrients. The ratio of nitrogen in the associated fertilizers to straw was chosen to conform with the Hutchinson and Richards " nitrogen factor " (0·75 parts N per 100 parts straw), as a conventional estimate of the amount of additional nitrogen likely to be immobilized by the straw in the soil or the compost heap. The compost was made by soaking the straw in water, adding calcium cyanamide and ground phosphate rock with some calcium carbonate when stacking the moistened straw in the open. The compost was put up about May and ploughed in about November at the same time as the chopped straw on other plots. The fertilizers were applied as ammonium sulphate, superphosphate and potassium chloride, except that the basal dressing for sugar beet was given as sodium nitrate and the potassium for potatoes as sulphate. For potatoes the fertilizers applied in spring were placed in the furrows immediately before planting the sets and splitting back the ridges.

The yields for the period 1934 to 1951 inclusive give three full six-year cycles with nine repetitions of the manurial treatments and six seasons for each of the three crops.

Table 1 gives the mean yields for eighteen seasons for each of the three crops, distinguishing those with high fertilizer dressings (with straw or compost on some plots) applied for the test crop and those with low fertilizer dressings without straw or compost, following high dressings to the preceding crops.

The first part of Table 1 shows the immediate and the first year residual effects of the four manurial treatments. The yields of barley, both grain and straw, were reduced appreciably by straw and markedly by compost ploughed in during the autumn. Straw and compost applied for the potato crop had only small and irregular residual effects on the following barley crop. Sugar beet showed similar results, the yields of roots, sugar and tops being reduced appreciably by straw and markedly by compost applied in the previous autumn but scarcely affected by residues from the straw and compost applied for the preceding barley crop.

It is known from another experiment over the same period in the same field (Six-course Rotation) that barley and sugar beet show large responses to nitrogen and small ones to phosphorus or potassium. The effects of straw and compost on barley and sugar beet can be largely explained by the simple assumption that the crops suffered through loss of available nitrogen where straw was applied either directly or in compost. Indeed, the losses in composting agree fairly well with the Hutchinson and Richards factor, assuming that none of the nitrogen immobilized was recovered subsequently. Fifty-three cwt. straw per acre with 0·4 cwt. nitrogen per acre made into compost gave almost the same yields (to within 1 per cent) as plots receiving no additional fertilizer. The loss of available nitrogen was presumably less on the plots where straw was ploughed in directly, because the straw may have used some nitrate which would otherwise have been lost in drainage. Where half or all of the

fertilizer nitrogen was applied in the spring, some would be used by the crops before the straw could remove it.

Potatoes behaved quite differently from barley and sugar beet. The potatoes showed a gain of about 10 cwt. per acre from straw ploughed in in the previous autumn, provided that the fertilizers were all given to the potato crop in spring, and also good gains from residues of the straw applied for the sugar beet crop (20 cwt. potatoes per acre from straw residues and 12 cwt. from compost residues). At first sight this might suggest that the potato crop responded to some improvement in soil structure. There are, however, strong indications that some other factor was responsible. It is known from the six-course rotation experiment in the same field that potatoes respond particularly well on this soil to additional potassium. The effects of straw and compost on the potato crop may well represent the combined effect of a loss of available nitrogen from straw or compost applied in the previous autumn, as was also shown in the two other crops, and a gain of potassium from the straw.

The second part of Table 1 shows the mean annual changes in yield for each treatment. If straw or compost progressively improved soil fertility, the treated plots would be expected to gain steadily on the untreated plots. There is, however, no general improvement over 18 years on plots receiving straw in alternate years. The only significant differences in the mean annual changes for the sets of four comparable figures tabulated are :

(*a*) for direct applications to potatoes, a progressive improvement for straw with fertilizers divided between winter and spring and also for compost ;

(*b*) for direct application to sugar beet a progressive fall with all straw treatments below those on plots without straw.

The barley crop showed only small and irregular effects of treatments on the slow changes in yield.

The contrasted responses of potatoes and sugar beet to straw and compost are illustrated in Table 2 by estimated yields for the first and last season of the experiment, calculated from the mean yields and the mean annual changes.

At the beginning of the experiment straw applied for the potato crop increased yields if the fertilizers were given in spring, but decreased them if the fertilizers were divided between autumn and spring. At the end of the experiment these two treatments gave similar improvements of about 10 cwts. potatoes per acre. There is little reason to expect soil structure or soil organic matter to be much influenced by the time and method of applying fertilizers, but it is well known that putting fertilizers close to potato sets is much better than ploughing them in during the previous autumn. If the soils were gaining in available potassium through repeated treatment with straw, differences due to the time and method of applying the potassium fertilizer would become progressively less important. As straw with divided fertilizer dressings gave lower yields of potatoes than straw with fertilizers in spring in the early years of the experiment, more potassium would be left unused in the soil. Both at the beginning and the end of the experiment straw residues gave a much bigger increase than the direct applications because in the residual year there would be much less loss of available nitrogen. It would

scarcely be expected that structural or organic matter effects from straw residues would be greater than those from straw applied directly for the potato crop. The compost continued to the end of the experiment to depress yields markedly in the year of application but the gain from the residues increased as time went on.

Analyses of the materials throughout the experiment showed that the average straw dressing supplied about 0·6 cwt. K_2O per acre, and the average compost dressing about 0·3 cwt. K_2O per acre. The increases in yield of potatoes for treatments applied for the preceding sugar beet crop were about half as large for compost as for straw, both at the beginning and the end of the experiment. This suggests that the potassium supplied accounted for a large part of any benefit from straw or compost on potatoes.

At the commencement of the experiment the yields of sugar from sugar beet showed little effect from straw or its residues and a small depression from compost applied in the preceding autumn. By the end of the experiment yields were reduced considerably by straw and by compost applied in the preceding autumn. The residues from straw or compost applied for the barley crop had only small effects at any time. The tops of sugar beet showed only very small and irregular progressive changes, the average effects throughout the experiment being similar to those for roots and sugar at the end of the experiment.

As was stated in discussing the mean yields, the effects on sugar beet can be explained by assuming that the main effect of straw or compost is to reduce the supply of nitrogen available to the sugar beet crop. By the end of the experiment the plots with compost from straw and 0·6 cwt. N per acre in fertilizer gave lower yields of sugar than those with 0·2 cwt. N per acre in fertilizer. This tends to confirm a suggestion from other work that straw may immobilize more than 0·75 per cent of additional nitrogen.

Straw may influence soil fertility in so many ways that no simple explanations can be offered for all the results for three crops testing immediate and residual effects over 18 seasons. It is, however, clear that there is no sign of any general improvement in soil fertility through adding large amounts of straw. It may be dangerously misleading to regard straw as the basis for maintaining soil fertility. Straw reduced yields of two of the three crops tested and for sugar beet roots the reductions became more severe as the experiment progressed. Losses were particularly serious where nitrogen and phosphorus fertilizers were used to make straw compost instead of being applied directly to the land. Where straw is applied directly it may be assumed that about one part of extra nitrogen will be required for every 100 parts of straw to prevent serious loss of nitrogen available to crops. The extra nitrogen should be given at the time most suitable for the following crop. There is little sign that the nitrogen immobilized by straw becomes available later in any significant amount.

Provided extra nitrogen fertilizer is used to balance the losses caused by straw, the potassium in the straw may add appreciably to the supply in the soil. The potassium content of straw is very variable; in this experiment the range was from 0·6 to 1·8 K_2O per cent of the dry matter.

The interpretations offered above for the effects of straw and compost are being examined more closely by soil analyses and by continuing the experiment in a revised form which will allow tests on straw with extra nitrogen against additional potassium fertilizers. This may allow a clearer opportunity for detecting any physical or other effects from the additional organic matter which may have hitherto been missed.

TABLE 1

Mean yields and mean annual changes in yield, 1934 *to* 1951

Sugar beet roots and tops, potatoes in tons per acre
Barley grain and straw, sugar in cwts. per acre

	Barley		Sugar beet			Potatoes
	Grain	Straw	Roots	Sugar	Tops	
Mean yield :						
Application to test crop						
F	32·3	37·5	11·7	43·3	10·5	9·12
Ss	30·8	34·6	10·9	41·0	9·2	9·64
Sw	30·8	33·4	10·9	40·9	9·0	9·25
C	27·5	29·7	9·9	36·9	7·9	8·00
Application to preceding crop						
F	27·4	29·4	10·0	37·3	7·9	6·99
Ss	27·3	29·5	10·0	37·4	7·8	8·02
Sw	28·0	30·1	10·3	38·6	8·2	8·11
C	26·3	28·8	9·7	36·1	7·8	7·58
S.E. ...	±0·55	—	—	±0·68	±0·23	±0·137
Mean annual change in yield :						
Application to test crop						
F	—0·01	—0·28	0·12	0·42	—0·06	0·06
Ss	—0·11	—0·19	0·05	0·13	—0·11	0·06
Sw	—0·10	—0·15	0·00	—0·11	—0·13	0·13
C	—0·11	—0·28	0·03	0·06	—0·08	0·12
Application to preceding crop						
F	—0·19	—0·28	0·06	0·18	—0·11	0·08
Ss	—0·09	—0·21	0·02	—0·01	—0·06	0·10
Sw	—0·09	—0·24	0·04	0·07	—0·06	0·14
C	—0·05	—0·16	0·00	—0·03	—0·11	0·11
S.E. ...	±0·065	—	—	±0·101	±0·028	±0·019

TABLE 2

Estimated smoothed yields

Treatment	*First year* Application to : test crop	*First year* Application to : preceding crop	*Eighteenth year* Application to : test crop	*Eighteenth year* Application to : preceding crop
Potatoes, tons per acre (±0·21) :				
F fertilizers	8·6	6·3	9·7	7·7
Ss straw, fertilizers in spring ...	9·2	7·1	10·1	8·9
Sw straw, fertilizers divided ...	8·2	7·0	10·3	9·3
C compost	7·0	6·7	9·0	8·5
Sugar, cwt. per acre (±1·10) :				
F fertilizers	39·7	35·8	46·9	38·8
Ss straw, fertilizers in spring ...	39·9	37·5	42·1	37·3
Sw straw, fertilizers divided ...	41·8	38·0	40·0	39·2
C compost	36·4	36·4	37·4	35·8

THE FARMS

By J. R. Moffatt

Rothamsted

The year under review was one of the most difficult and disappointing ones ever experienced. We had hardly recovered from the disastrous weather conditions of the 1950 harvest before a prolonged wet spell set in again. This not only considerably reduced the area of winter corn that could be sown, but also considerably delayed the harvesting of the root crops in 1950 and the ploughing for spring crops. The wet spell continued almost unbroken until mid-April, 1951, and land work started six weeks later than usual. In the first four months of 1951 the rainfall was more than 6 in. above the average. Thereafter it was a rush to get the spring crops sown. Thanks are due to all members of the farm staff who willingly worked very long hours to get through the work. June and July were dry, during which time all crops made rapid growth, but the two main harvesting months of August and September were again very wet, and the crops had to be gathered as best they could. October brought a pleasant respite, and potato lifting and autumn ploughing and drilling got a good start in dry weather. However, before the end of the month the weather again broke, with corn drilling still far from completed. A three-day fine spell early in December presented the only opportunity for drilling between the end of October and the end of the year. The 1952 cropping scheme has therefore had to be revised because of the unfavourable autumn weather.

Field Experiments

The unfavourable weather conditions in autumn and spring caused the abandonment of one experiment, and the revision of some spring experiments, but even so, the number of experimental field plots increased by 440 to a total of 2,007. The late start of spring field work made the planning of the programme of work very difficult, but the whole programme was eventually carried through. The gradual increase in the mechanization of experimental field work over the past few years enabled this programme to be very much bigger than would have been possible a few years ago. The potato crops on three of the long-term rotational experiments were planted very successfully by dropper this year, but in order to retain the same relative position of seed and fertilizer as in the past, two of these experiments will revert to hand planting in future.

Cropping

Of the 474 acres farmed, 251 acres were under arable crops, and 111 acres under grass and clover leys. The main crops were ; wheat, 105 acres, barley 61 acres, oats 10 acres, linseed 12 acres, potatoes 23 acres, kale and mangolds 18 acres. Other crops included beans, rye, and sugar beet, lucerne and vegetables, while 8 acres of experimental land were under bare fallow.

Crop Varieties

Wheat

Six varieties were grown. Squareheadsmaster 13/4 and Yeoman

were grown on experimental areas, Bersée and Nord Desprez on non-experimental fields, and a very small area of Petit Quin Quin was grown to keep a stock of the seed. A small area of Atle was sown in the spring. As Nord Desprez seems to be more suitable for combine harvesting than Bersée, the latter variety will not be grown in 1952, except on some experimental areas. Petit Quin Quin showed signs of acute nigrogen starvation, and consequently gave a low yield. This variety will be tried out again under the conditions of high fertility it seems to require.

Barley

Plumage Archer was grown on all areas except for a small 2-acre patch of Herta. This ripened earlier than did the Plumage Archer, stood better and gave an excellent yield. The area under this variety will be considerably increased in 1952.

Oats

Sun 11 was the only variety grown. The crop was sown very late, and consequently proved disappointing. The variety has done well in the past, however, and will be retained in the future. White Opus will also be tried out in 1952.

Rye

The small area of rye was planted with King II, as the shorter straw makes for easier harvesting than the long-strawed varieties.

Linseed

With the introduction of Valuta, a rapid-growing and heavy-yielding variety, bred at Svalof, it was decided to sow a field of this variety. A satisfactory crop resulted and some of the seed will be sown again in 1952. The crop was inspected by the Seed Production Committee under the new Linseed Certification Scheme.

Potatoes

Majestic is the only variety grown ; as it is the standard variety grown on experimental plots it is also grown on non-experimental areas. It yields well, is less susceptible to Late Blight than some varieties, and stores well. New seed is purchased each year, and in past years Grade A has been used for experimental work, and for most of the non-experimental areas but with occasional areas of grade H seed. Starting in 1952, however, Stock Seed will be used on all experimental plots, and Grade A seed on all non-experimental areas.

Crop Growth

Wheat

The winter wheat generally survived the wet winter very well, and only a few small patches which were under water for a long time failed to survive. The heavy rains caused severe leaching of nitrogen during the winter and many of the crops continued to show symptoms of this throughout the summer. The top-dressings of nitrogen were applied much later than usual, as it was considered more important to get the spring crops sown. The eventual application of these dressings coincided with a spell of dry weather, and the crops showed no response for some time. This dressing did not

appear to have been heavy enough, and further applications were given to several fields. Yields, however, were below average.

Barley

Spring barley looked more promising than did the wheat, but it came into ear later than usual and some fields ripened very unevenly. Yields varied from field to field, but were generally satisfactory, and although not of very good quality, all the grain was sold for malting.

Oats

This was the most disappointing crop of the year. Growth was slow after a very late start, and the crop appeared stunted throughout the season. This was probably due to a shortage of nitrogen, although the crop received $1\frac{3}{4}$ cwt. per acre of sulphate of ammonia early in June, in addition to $1\frac{1}{4}$ cwt. per acre of superphosphate at time of sowing. The ears seemed to ripen prematurely while the straw was still unripe, which led to difficulty at harvest time.

Potatoes

Nearly all the planting of this crop was done with a dropper attached to the toolbar of a ridging plough. Despite their late start, growth of the plants was maintained at a satisfactory rate, and two sprayings with a low-volume sprayer against Light Blight kept the tops green until almost the end of September. Burning off was then carried out using sulphuric acid. Tests were also made with several alternative materials for burning off, and also with a mechanical haulm destructer, but sulphuric acid proved easily the most effective. The lifting of the crop was completed before the end of November, the picking being done by school children. Yields were below normal, but the tubers were of good size and shape. They were stored as usual in a large heap in the barns.

Experiments in progress indicate that the yields from plots planted with a dropper are superior to those from hand-planting, probably partly due to the fact that a bigger proportion of the tubers survive when a dropper is used.

Sugar beet

Only a very small acreage was grown, as there is always difficulty in getting the singling done at the proper time because of the pressure of experimental work, and the expense of getting the crop lifted, cleaned, and carted off our heavy soil is considerable. The crop maintained good growth throughout the summer, and there was little Virus Yellows disease. The leaf : root ratio was rather higher than usual ; the sugar content averaged about 16·5 per cent.

Kale

This crop made splendid growth throughout the season, and was one of the heaviest ever grown. The seedlings were sprayed with a low-volume machine using 15 per cent D.D.T. emulsion to ward off a threatened fleabeetle attack.

Mangolds

This crop is only grown on the classical experiment on Barnfield

where it has been grown since 1876. The application of fertilizers to plots and the drilling occupy a full week. Consequently in recent years this work has been left until towards the end of the spring programme, and the crop has been sown late for many years. In future the crop will be given a certain amount of precedence over annual experiments. In 1951 it was sown very late (May 26th) and subsequent growth was slow. Together, this affected the yield, which was very low.

Linseed

The new Swedish variety Valuta grew rapidly after a late start. A rather late inspection of the field showed a considerable growth of Cleavers (*Galium aparine*) and creeping thistles, so the crop was sprayed with M.C.P.A. weedkiller at a rather forward state of growth. The tractor wheels and the spray both caused some damage to the crop, and although it recovered, the yield was probably affected. A dressing of nitrogen was given in early June.

Harvesting

All crops ripened much later than usual and very unevenly. Weather conditions during harvest were very bad, and the operation was prolonged until early in October. A 50-hole platform-type grain drier proved a tremendous boon, as nearly all the combined grain needed drying. The provision of the drier enabled fuller use to be made of the combine than has been possible in the past. No moisture meter was used, but difficulty in estimating the moisture content of the grain showed the need for one.

The potato harvest was carried out under excellent conditions in October although an increase in the number of experimental plots prolonged this operation beyond the usual length of time.

For the sugar beet and mangold lifting, weather conditions were atrocious, the month of November having a rainfall of almost twice average. Lifting was completed by mid-December.

Grassland

The season suited the grassland well, and there was ample keep throughout the season. The heavy rainfall in August and September enabled the grass to maintain growth well into the autumn, and supplementary feeding was not needed until later than usual.

About 10 acres of old grassland were ploughed up and will be put through an arable rotation, and about the same acreage of arable land was put down to a long-term ley.

Several fields were sprayed with a hormone-type weedkiller, to control buttercups and thistles.

Hay crops were mostly very satisfactory; they were mainly baled and carried to the barns.

The wet spring caused a big flush of grass on the 2nd and 3rd year grazing plots on the Ley-arable experiments, but owing to pressure of other work in the late spring, the experimental grazing of these plots could not be undertaken immediately, and it was therefore decided to take an early hay crop from them and graze them subsequently.

All the under-sown seeds took very well, both on experimental plots and on non-experimental areas.

Livestock

Cattle

The cattle policy is to purchase young Hereford-cross cattle, winter them fairly cheaply on home-grown produce, and fatten them off the grass at about two and a half years old. They are wintered mainly in covered yards where they are fed on oat and barley straw, hay and kale, with a small supplement of home-produced grains. They produce sufficient farmyard manure for experimental plots and for the 20-30 acres of potatoes grown each year. During 1951, 60 beasts were sold fat.

Sheep

The ewe flock of about 150 ewes, originally a flock of Scotch Half-breds, is now composed almost entirely of second cross ewes (Oxford and Suffolk × Scotch Half-bred). They are mated with rams of Down breeds for the production of fat lambs.

The lambs did not thrive as they should have done, and very few were sold fat by the end of September. Many of them were sold as store lambs in October, though sufficient were retained for stocking the grazing plots at Rothamsted and Woburn in 1952.

After the 1952 season the flock will be reduced to the minimum size needed to produce the sheep required for grazing experiments.

Machinery

The range of implements has been increased during the year by the purchase of a third tractor fitted with hydraulic lift, which will mainly be used on experimental field work. An electrically-heated platform-type grain drier with a capacity of 50 sacks has been installed, and a grain cleaner has also been purchased, to enable grain to be cleaned well enough for seed purposes. Other new items include a mounted 2-furrow reversible plough, a mounted low-volume spraying machine, and a mounted weeder.

Buildings

The only addition to the range of buildings has been a large general purpose building 150 feet long by 33 feet deep. This now houses the grain drier, but it is mainly used as an implement shed. It will also be used to store grain and fertilizers.

Estate Work

A considerable amount of estate maintenance work was carried out during the year. This included hedging, fencing, and the felling of dead trees for cutting into timber.

Staff

Mr. H. P. Currant, the farm bailiff, was awarded the Long Service Medal of the Royal Agricultural Society of England for 40 years' service with the Station. This long period of cheerful and unstinted service has greatly facilitated the smooth running of the farm.

Mr. J. Bidgood and Mr. W. Cooper joined the staff as recorders of experimental field plot work.

Mr. L. Wright, a horseman of 7 years' service, died after a long illness.

Mr. J. R. Moffatt was given a grant by the Agricultural Research

Council to enable him to make a tour of research stations and experimental farms in Holland, Denmark and Sweden.

Woburn

The Woburn Farm was directed and managed by the staff of the Rothamsted Farm, the day-to-day planning being left largely to the foreman at Woburn.

Owing to the shortage of permanent staff, no annual experiments were undertaken, but the number of experimental plots was increased by 96 plots on a new long-term experiment testing the value of overhead irrigation for farm crops. The total number of experimental plots scheduled was 538, and, despite the late spring, the full programme of work was carried through.

Of the 127 acres farmed, cereals occupied 60 acres, potatoes 22 acres, sugar beet 6 acres, and grass 24 acres. The remaining area was under experimental crops and fallow. The singling and harvesting of the small acreage of sugar beet presented difficulties because of the labour shortage, and the quality of the work was poor. As labour difficulties become more acute each year, the growing of sugar beet, in future, will be restricted almost entirely to experimental areas. The potato crop does not present such great labour problems, and the area under this crop will probably be increased.

Further progress was made with the mechanization of field and farmstead operations by the purchase of a mechanical dung loader and a dung spreader, while a sack elevator has greatly facilitated the handling of sacks of corn, potatoes, and feeding stuffs around the farmstead.

The buildings were patched and painted during the summer for the first time for over 20 years. Plans are now well forward for the erection of a pair of farm workers' cottages on the farm, and when these materialize many of the immediate labour problems should be solved.

The very heavy rain during the winter caused some of the heavier fields to become waterlogged, but cleaning many of the ditches considerably eased the position. Many of the badly overgrown hedges received attention during the winter, and it is hoped that during 1952 the last of them will have been dealt with.

The year was generally a very difficult and disappointing one. The abnormally long wet autumn and winter of 1950-51 considerably retarded normal winter land work, and delayed the start of spring operations by about six weeks. When land work started in the middle of April there were considerable arrears to be made up, as well as normal spring cultivations and sowing to be done. The lateness of the season made necessary a revision of cropping plans as it was considered too late to sow spring oats or wheat.

The surface of the land dried out very rapidly during April and May, until a point was reached where the seed-beds were too rough for sowing because of the too rapid drying of the surface, while other fields were too wet below the surface even for ploughing. However, by the middle of June work was up to schedule, although all crops were backward as a result of late sowing.

Nitrogenous top-dressings were applied both to winter and spring cereals much later than usual, because drilling and planting were given precedence. These late applications of nitrogen unfortunately co-incided with a dry spell and did not get washed in for some time, and when they later became available to the plants, the dressings proved inadequate, presumably due to the heavy leaching of nitrogen from the soil during winter and spring. A second application was therefore given to winter corn but this appeared to have little effect. Many of the corn crops were consequently disappointing.

The permanent wheat looked quite well throughout the year but the effect of different levels of " Nitrochalk " was not nearly as clear as usual. Some wild oats appeared but these were hand-picked. The area was sprayed with D.N.O.C. at medium volume at a rather late stage of growth, and with rather disappointing effects, especially on mayweed. The Permanent Barley ground was smothered by spurrey and the crops made little headway against the weed. Spraying with D.N.O.C. had very little effect and many of the plots were abandoned.

The corn harvest began very late and because of bad weather conditions became a very difficult and protracted operation continuing intermittently until the end of September. It had been hoped to thresh much of the corn in the field but the weather conditions made this impossible. One field of spring barley was not cut until the middle of September and even then it was far from ripe.

The weather throughout June and much of July was dry, and this considerably delayed the transplanting of the winter cabbage and leeks on experimental areas, and retarded the " take " of these crops. Several patchings were needed before a full plant was secured.

The experiment on market garden crops underwent a revision this year by the elimination of the pea crop. Three crops instead of four are now grown in two years, the new rotation being red beet, spring cabbage and leeks. It is fortunate the change was made this year as it would have been impossible for two crops to grow to maturity. The spring cabbages in this experiment were severely damaged by leather jackets, and the whole area had to be sprayed with D.D.T. before a full plant could be established, despite several patchings.

A large area of non-experimental potatoes was grown, planting being done by a dropper attached to the frame of a 3-row ridger. The crop made fairly rapid growth throughout the summer, and was kept clean entirely by mechanical operations. Two sprayings against Late Blight (*Phytopthora infestans*) enabled the crop to maintain growth until the end of September when the haulm was burnt off with sulphuric acid. Lifting operations were carried out under excellent weather conditions until towards the end of October, but heavy rain throughout November prevented the completion of this work until early December. Three severe frosts early in December penetrated to a fair proportion of the tubers in the soil. The tubers seem to be more severely affected by Common Scab

(*Actinomyces* sp.) than usual. Despite the precautions taken there was also some blight in the stored tubers.

The non-experimental sugar beet crop made good growth after a very late start and there was very little infection by Virus Yellows disease. However, there was a high proportion of leaf to root, and yields were lower than was anticipated. Most of the area was harvested mechanically with reasonably good results. The sugar content averaged about 16 per cent.

A new experiment testing three levels of overhead irrigation with no irrigation on a rotation of farm crops was started in the spring. The rotation is early potatoes followed by winter cabbage, barley, and sugar beet, each crop being grown every year. A fourth crop is a 3-year grass ley cut several times each year when 4-6 in. high. The plots are split for testing two levels of nitrogenous fertilizers. The experiment made a very satisfactory start, all crops growing and yielding well.

The autumn ploughing for winter corn was well advanced and all experimental plots were drilled before the weather broke again during the last week of October. Some non-experimental areas had also been drilled, but the bulk of the winter wheat was planned to follow potatoes. The wet weather which persisted throughout November and well into December ruled out this possibility and changes in the cropping plans for 1952 had to be made.

The small herd of Large White pigs was increased slightly during the year by retaining a few home-bred gilts for breeding purposes. All the progeny were carried on to bacon weight; they were fed largely on barley grown at Rothamsted or Woburn, and home grown stockfeed potatoes. The maturity indices and grading were very satisfactory but the killing-out percentage was in many cases rather low.

Some of the Irish cross-bred bullocks were out-wintered, while others were yarded to make farmyard manure. They were fed almost exclusively on sugar beet tops, and straw, with a small supplement of sugar beet pulp and offal grain. Half of them were fattened off from the grass at Woburn, the remainder being transferred to Rothamsted.

WOBURN EXPERIMENTAL STATION

By H. H. Mann

Season

The year 1951 was the second in succession with an abnormally large rainfall at Woburn, and this exceeded even the earlier year in amount in almost every month. This was accompanied by coldness in almost every month, where, except in July, the mean temperature was even lower than in the previous year. This condition of things prevailed until September, 1951, after which, if anything, the season was a little warmer than usual. The spring was especially wet, leading to very late sowing or planting of spring crops, and being specially unfavourable for the semi-tropical exotic crops which are one of the special studies at Woburn. The meteorological records from October, 1950, to the end of 1951 are shown below.

Meteorological Records for 1950-51

Month	Rainfall			Temperature			
	Total fall	No. of rainy days	Bright sunshine	Max.	Min.	1 ft. in ground	Grass Min.
1950	ins.		hours	F.	F.	F.	F.
October	0·50	6	105·0	55·5	42·3	49·9	38·6
November	4·27	22	60·2	47·4	36·6	42·8	33·7
December	1·40	16	36·5	37·0	28·5	35·8	27·1
1951							
January	2·57	17	44·4	43·4	33·6	37·7	31·4
February	3·54	21	65·9	43·0	33·3	37·3	30·4
March	3·46	21	92·0	45·1	33·3	39·5	31·2
April	3·02	12	184·9	52·4	35·4	44·6	33·0
May	2·41	15	144·3	57·4	42·4	50·5	41·2
June	0·83	11	242·9	66·6	47·1	59·5	43·5
July	1·76	10	190·9	71·5	51·5	64·8	45·0
August	3·77	20	171·0	67·0	51·5	61·0	45·9
September	2·05	13	119·6	64·9	50·2	57·4	44·8
October	1·24	11	100·8	55·8	39·2	49·0	34·8
November	4·35	26	62·9	51·8	41·9	45·9	37·1
December	1·56	16	60·8	47·0	35·7	41·0	31·4
Total or mean for 1951	30·56	193	1480·4	55·5	41·3	49·0	37·5

Field Experiments

The field experiments at Woburn are now conducted under the direction of the Field Plots Committee at Rothamsted, and that Committee will report separately on them. There are, however, a few points in connection with them which may be recorded here.

In the last report mention was made of the fact that, even after three years of fallowing accompanied with intense cultivation, a crop of barley was almost smothered by the weed *Spergula arvensis* (spurrey), which had previously infested the land. The same ground was again sown with barley in 1951 and again spurrey appeared in very large amount and on most of the plots apparently almost smothered the barley. It is clear that, with this weed at any rate, fallowing, even with almost continuous cultivation, will not, even in four years, get rid of the weed. It is also fairly resistant to most

of the herbicides now in use and furnishes one of the continuing troubles on the light semi-acid soils at Woburn.

I might mention, in connection with weeds, the comparatively recent appearance of another acid-loving weed on the permanent wheat plots at Woburn. This is *Scleranthus annuus* (knawel) which was first noticed on the plots which had become acid by continued treatment with sulphate of ammonia a very few years ago. Though this area has been under no other crop but wheat since 1877, yet when I studied the weeds on the various plots 20 years ago, this weed was not found at all. Now, it is rapidly spreading over the area especially on the plots which have till recently, never received nitrogenous manures either in the form of nitrate of soda or farmyard manure.

The Woburn studies of weeds by pot culture have now been extended to the more general question of the influence of one plant on another and a paper is now in the press on the mutual effect of barley and clover when sown together under conditions made as favourable as possible for the barley, as is usually the case when barley is undersown with clover. These conditions involve a nitrogenous dressing to ensure a full crop of barley and so remove any question of its dependence on the clover roots for the nitrogen which it needs. This being the case, the two plants, at every thickness of planting, act as pure competitors, the presence of the clover acting as a reducer of the barley, while the barley, still more markedly, reduces the growth of the clover till after the corn crop is removed.

New Crops

As noted in previous reports, one of the matters which have been, for a number of years, a feature of the Woburn Station is the growing of certain exotic crops which seem to have possibilities in this country especially on the well-drained and semi-acid soil which is characteristic of the Woburn Station. For such of these crops, like hybrid maize and soya beans, as are accustomed to a hot season for growing, the year has been an exceedingly unfavourable one. The absence of any real spring, with ground saturated with water, delayed the planting of these crops nearly a month—a fatal incident in attempting to grow crops which have difficulty in ripening in the English climate. The Swedish soya beans, which seem the most promising for this country, and a Dutch variety of similar type, have nevertheless ripened without difficulty even in 1951, but it seems difficult to obtain a yield of more than about 10 cwt. of dry beans per acre in such cool and wet seasons, as compared with over 14 cwt. in a more suitable year such as 1949. As noted in my last report, it seems difficult to get properly nodulated roots of soya beans in such a wet year in spite of careful inoculation of the seed. The possibility of finding a variety and a method of cultivation suitable for Britain remains doubtful.

A year ago I reported on the successful growing of some of the early varieties of hybrid maize, obtained from the United States, in three successive years, with an average yield of dry grain of 32·5 cwt. per acre. In the even more unfavourable year 1951, the same varieties grew quite well and, in addition, we have obtained equal results from similar types bred in Holland. Two great difficulties

have been emphasized in the present year. The first of these is the necessity of sowing early, say not later than the first week in May, if ripening is to take place before the wet autumn days in October. The other is the great danger of birds and vermin at every stage of the crop. When maize is just appearing above ground it seems to have an extraordinary attraction for birds and this year I lost a good part of my crop on this account : when the corn is ripening, again, there seems great danger of the grain being picked out from the cob. In consequence it would seem that the future of the growing of maize for grain in this country is as a small-holders' crop to fill in small areas near houses where any other grain would be unsuitable, and to use the grain, without threshing, for feeding chickens and the like. For this purpose there is no longer any doubt that these early hybrid maizes may be of great advantage in this country.

Another set of crops which have been grown at Woburn in 1951 are sweet lupins and some other fodder crops which grow quickly and which can be so cultivated as to give a large amount of fodder about the end of August when the grass in pastures is beginning to reduce its yield. There are several such crops which are suitable for chalk soils, such as sainfoin, but for semi-acid light soils, such as that at Woburn, there is definitely a deficiency. For such conditions, however, sweet lupins seem to fill the gap, at any rate in summers when the weather is not too dry. This year we have grown four different types of sweet lupins, and three of them have given yields and edible produce which would seem to make them worth far more widespread cultivation than they have yet received. The position in the country up to 1950 has been well summarized in a recent article by A. W. Oldershaw. This year the several varieties were sown at Woburn on May 16th. They were (1) Weiko, grown from our own seed produced in 1950, (2) Nobe, (3) Neven and (4) Namar, the last three being grown from seed obtained from the National Institute of Agricultural Botany. These were all, except the last, varieties with yellow flowers, No. 4 being a blue type. I may say at once that the blue variety, as in previous years, proved so susceptible to the wilt fungus (*Fusarium avenaceum*) that it was useless. Most of the plants after growing healthily up to flowering, then began to wilt and within a month almost all the plants had died. The yellow types seemed almost if not entirely immune to this blight, and grew well. By the latter part of August, they had given a thick heavy growth of green stuff, had flowered and were forming pods though these were still in the green stage. They were then cut and gave yields as follows :—

1951 Variety	Weight of Green Stuff per acre tons	Dry Matter in Green per cent
Weiko	14·1	12·6
Nobe	22·2	12·1
Neven	26·4	12·1

The yield of Weiko followed a production of 17 tons of green stuff in 1950, so that in a wet year there is no doubt that a very heavy yield of green fodder can be obtained from good strains of sweet lupins on land such as we have at Woburn. The fodder is not very palatable to stock, but it was eaten after some hesitation, and would doubtless

be accepted willingly if fodder were otherwise short. All the varieties seeded profusely and though we lost most of our seed this year by vermin, yet there will be no real difficulty in obtaining a good amount of seed from a comparatively small plot.

Two other leguminous fodder crops which we have tried for a similar purpose as sweet lupins, and for a similar class of land, are serradella and birdsfoot trefoil, both of which have been very successful in 1951. The former, which had given a yield of 11·6 tons of green fodder (containing dry matter 15·7 per cent) on August 16th in 1950, this year gave 6·8 tons (containing dry matter 16·6 per cent) on August 23rd but the fodder was greedily consumed by grazing animals. Before cutting, enough seed had fallen to give another green carpet by October, and the growth continued till a really heavy frost occurred in the early winter.

As regards birdsfoot trefoil, which was sown on May 17th, a crop of 9·7 tons of green fodder per acre was reaped at the beginning of November. This crop grew very slowly at the beginning and till the late summer did not seem likely to give a serviceable yield, but finally it covered the ground well and was still growing vigorously when cut. Birdsfoot trefoil is a perennial, and it will be remembered that in the second year on a previous occasion (1950) it gave a yield of 19·4 tons of green fodder per acre in July.

Altogether, we seem to have reached a point when several fodder crops which will grow on light semi-acid land have been obtained which can be relied on, at least in a moderately wet season, to give a good yield of green fodder in the autumn when the normal sources are tending to decline.

Irrigation Experiments

In my last report I noted that it was intended to initiate experiments on the value of spray irrigation for several of the ordinarily grown farm crops. This intention was carried out in the spring of 1951 and a large series of experiments with early potatoes, sugar beet, barley, cabbages and freshly sown grass were started. The actual direction of the experiment has been with Dr. Penman of the Rothamsted Physics Department, and that department will report on the results, both as to the amount of water which it was necessary to use and on the crops obtained. I may, however, say here that, even in a wet season like 1951, in every case (except with the cabbages which are not yet reaped at the time of writing) substantial benefit was obtained in the crop as a result of the watering. This was especially the case with the yield of early potatoes and with the first and second crops of grass. Woburn is particularly suitable for such an experiment with its light sandy loam soil, over sand, without any watertable within a good many feet of depth.

Pot Experiments

Clover Sickness

One of the chief objects of study in the pot culture station for the last 15 years has been the partial or complete failure of clover when it is frequently grown on the same land, even in the absence of any

known parasite. The explanation of this failure is at last becoming clearer and the results obtained in 1951 have made it possible to formulate, at least provisionally, conclusions on which we can base further experiments. These conclusions are as follows: (1) The failure of clover is due to an exudate from the roots of the living clover plant, which is toxic to clover, particularly to young clover plants, is sensitive to heat, cannot be readily washed out of the soil, and is not easily oxidized. (2) Partial sterilization of the soil, except by heat, but by such materials as toluene or formalin, has very little effect on the sickness of the soil or on its capacity to grow clover. (3) Soil which is toxic to growing clover shows little or no toxicity to gramineous plants such as barley or Italian ryegrass, but, on the other hand, it is very toxic to lettuce, radishes, or spinach beet. (4) Failure of clover does not seem to be due to any product of rotting either of clover roots or of buried clover tops. In the presence of a large amount of such rotting material perfectly normal plants of clover are obtained, though there seems to be some retardation of growth. (5) The addition of certain, though not all, colloid materials to the soil tends to reduce its toxicity to clover, though it has not been possible by this means to bring back soil to a completely non-toxic state. It is possible that the beneficial effect of farmyard manure may in part be due to its colloid constituents. On the other hand, a purely inorganic colloid like bentonite had no similar effect.

It will be seen that we have not yet been able to isolate the toxic material and determine its nature. This will be the next stage in the inquiry, together with a determination of the possibility that crops, such as the grasses, not affected by it, can be used to destroy this toxic material rapidly in the soil.

The nutrition of crops under very acid conditions

The work on this question, which has been one of the main concerns of the Woburn Station for a number of years, has continued in 1951. It was intended to publish the results up to 1950 but certain doubtful points emerged and it was decided to carry on another year's work before compiling the results. This is fortunate because it has become clear that certain contrasted effects on barley with calcium and sodium nitrate seem to depend very largely on the degree of acidity and on the amount of soluble sodium which is already there. At a pH value of 4·2, with little previous addition of sodium salts, sodium nitrate is always a more effective material on barley than is calcium nitrate: at a somewhat lower acidity, where such sodium has been added as sodium bicarbonate, calcium nitrate always gives a much more normal plant, while sodium nitrate led to a low growing bushy barley with much flabby soft leaf growth and only a few immature ears. The total results of the last three years of experiment are now being worked up.

Laboratory Work

The time of the laboratory staff has been taken up almost entirely with work in connection with the field and pot experiments. Most of this falls on Mr. Barnes and his staff, and they have been fully employed in these directions during the last year.

SOIL SURVEY OF ENGLAND AND WALES

By D. A. Osmond

In spite of many requests for soil maps of areas other than those where routine surveying is being continued, satisfactory progress has been made in the systematic surveys in Lancashire and Cambridgeshire and work has been started in Hertfordshire and Buckinghamshire on sheet 238 (Aylesbury).

Publication of the map and memoir of sheet 138 (Wem) should not be long delayed and the map and memoir of sheet 296 (Glastonbury) is in an advanced state of preparation. The soil map of Anglesey is being prepared for printing as sheet 106 (New Popular Edition). Revision of older work in North Wales is in progress with a view to its publication as a memoir.

Lancashire

Sheet 75 (*Preston*)

Detailed surveying was continued and about 30,000 acres mapped in three separate regions. The first is the lowlying land in the south-west of the sheet and consists of the alluvial flats of the Douglas and the moss lands to the west. Here the till covering most of the Lancashire plain is largely overlain by more recent deposits viz.: the Shirdley Hill Sand, which is probably a wind-blown material deposited against slight rises, and peat and alluvium.

Peat still covers by far the largest part of this area. It is mainly a basin peat—a black, pseudo-structural material with about 90 per cent of organic matter. The alluvial soils are extremely variable and several types have been recognized. The Shirdley Hill Sand appears to have been covered with peat and raw humus in the past and humus podzols are common on this parent material. The commonest series found are the Crannymoor and Sollam, though several others have been recognized and described.

The second area comprises Anglezarke, Heapey, Wheelton and Withnell Moors. Structurally it is a dissected plateau rising sharply from the plain and is formed of nearly horizontally bedded sandstones and shales, patchily covered with till. Those parts which were formerly enclosed have been mapped on a series basis but it proved necessary to group the soils on the open moorland into complexes. The dominant series in the enclosed fields are the Hallsworth, Brickfield and Anderton. The soils in the open moorland have been divided into peat over 3 ft. in depth, peat between 1 and 3 ft. thick and two complexes. One of these is dominated by soils developed from till that are shallow, very stony and patchily covered with less than 1 ft. of peat; the Brickfield and Belmont series are the most commonly occurring soils of this nature. The other complex is dominated by rocky and very shallow phases of soils of the Anglezarke, Rivington and Blindhurst series.

The third region surveyed is a continuation, as far north as Mellor, of the previously described area north-east of Chorley.

The soil picture is very similar though the large morainic deposits west of Blackburn give rise to fairly large areas of the Newport and Wem series, the latter in many places, showing a tendency to pass into humus podzols.

Cambridgeshire

Sheet 188 (*Cambridge*)

A further 30,000 acres have been surveyed by the team working on this sheet and approximately one-half of the map is complete. Two areas were surveyed, one lying north of Newmarket, around Chippenham, Freckenham and West Roe, the other being nearer Cambridge in the vicinity of the Wilbrahams, Bottisham and Lode. In both areas gently undulating downland with its higher levels covered with drift gives way to the level fens lying to the north-west. The more northerly district is drained by the Kennet and Snail while the southern area is drained by Swaffham Bulbeck Lode and the Little Wilbraham River leading through Quay Water into Botisham Lode.

Drift deposits in the northern district provide soils of both the brown earth and calcareous soil groups. The profiles are similar and consist of warm brown sandy clay loam, loam, or sandy loam, overlying brighter yellow-brown material of similar textures. The soils of lighter texture are sometimes slightly acid but in general the soils are calcareous and would be grouped with the calcareous soils. Lenticles of clay occasionally appear in the profile and the soils are often stony. In the southern area, the texture is often heavier, the colours are duller and calcium carbonate is almost invariably present.

Where free from drift, the Chalk Marl and Grey Chalk give rise to rendzinas of a clay loam texture, the surface soil being grey-brown in colour, the subsoil dull yellowish brown. In depressions, poorly drained soils with yellow-brown mottling in the subsoil are found. A series of soils consisting of a variable mixture of chalk with drift, frequently on sloping land, also occurs.

Gley soils have been recorded on the Gault clay and are succeeded by the fen which has a complicated soil pattern. Alluvial soils are developed on deposits from the Chalk Marl and sandy Chalk Marl, and other river deposits of variable texture, while peat or peaty loam, varying in thickness from 1 to 36 in. may be found overlying these as well as the Gault clay. Quarrying for phosphate nodules has resulted in many soils being disturbed.

Yorkshire

Sheets 70 (*Leeds*) *and* 71 (*Selby*)

Virtually no work has been done on these two sheets because of a request for an examination of a large number of restored opencast coal workings in the Midlands. The work will form part of a report to be issued shortly by the Statistics Department. It has been shown that profile studies can be of great value in elucidating problems likely to arise after restoration.

Hertfordshire and Buckinghamshire

Sheet 238 (*Aylesbury*)

The Hertfordshire portion of the sheet was covered during a reconnaissance survey in 1945 when 8,500 acres around Tring were

mapped in detail as a " sample " area. During the past year some 4,000 acres of woods and commons on the Chiltern Hills have been surveyed. The soils are derived from the Chalk and from Clay-with-Flints and associated drifts. Five principal series, namely, Icknield, Wallop, Winchester, Batcombe and Coombe have been distinguished, all of which but the last have been previously described.

Soils under beech-woods, which are essentially natural, have been investigated in detail and fall into four fairly well-defined major groups, viz. : rendzinas, brown earths of high and low base status, and slightly podzolized soils. Rendzinas, with a neutral to alkaline reaction, are found on the steepest slopes and have a dark greyish brown, very friable, mull-like A_1 horizon 4 to 7 in. thick grading through a brashy transitional layer, to hard chalk at 9 to 15 in.

Slightly acid to neutral brown earths of high base status with a very dark greyish brown, granular A_1 horizon of coarse mull and a brown B horizon of similar texture occur on thin Clay-with-Flints or flinty Head overlying Chalk or chalky down-wash at 9 to 15 in. Acid brown earths of low base status (pH 4·0 – 5·5) developed on thick plateau and valley drifts are by far the most extensive soils ; the profiles are characterized by the differentiation of brown or yellowish brown, relatively light textured, structureless and friable A horizons up to 15 in. thick, which become much greyer on drying. The A_1 is a fine mull rarely more than 4 in. thick. The B horizons are redder, firmer, cloddy and retain their colours when dry. In the slightly podzolized soils occurring locally on the plateau drift, the A_1 horizon of the brown earths is replaced by a very acid, black mor (pH 3·7 – 4·0) beneath which develops a narrow, discontinuous bleached A_2 horizon and a rusty-stained incipient B horizon. The onset of mor-formation appears to be favoured by a dense canopy which excludes other vegetation, but other factors including the base status of the parent material, natural drainage conditions, and the micro-climate, are among the prime causes.

Each stage in the succession from rendzinas to slightly podzolized soil is associated with change in the ground flora. Microbiological and faunal activity seem to reach a maximum in the high base status brown earths, but beech trees grow more vigorously on the rather more acid soils, probably because they are generally deeper.

Other Work

Collaboration has continued with the Veterinary Laboratory at Weybridge in investigating Johnnes disease, some farms having been surveyed and herbage samples collected for analysis. A number of farms have been surveyed for County Authorities, the National Agricultural Advisory Service and the National Institute of Botany and many maps have been prepared for the Agricultural Land Service (Wales). The survey of the Monmouth Moor undertaken for the Welsh Agricultural Land Sub-Commission was extended a short distance into the uplands. The first part of a catalogue of established soil series has been issued.

BEET YELLOWS VIRUS AND OTHER YELLOWING VIRUS DISEASES OF SUGAR BEET

By M. A. Watson

Introduction

Healthy sugar beet remain green until harvest. If they become yellowed it is because of deficiency of mineral nutrients, or infection by fungus, virus, or other pathogens (Hale, Watson and Hull, 1946). The most important cause of yellowing is beet yellows virus (Watson, 1940). Every year it causes serious losses of sugar in Europe, and in some years, when in large areas every plant may become infected, the losses amount to a considerable proportion of the potential yield.

Until recently the disease was thought to occur only in Europe, but yellowing diseases of sugar beet have now been reported from Australia (Stubbs, 1949) and from the United States of America by Dr. Hull on his recent visit. Whether these diseases are identical with that caused by beet yellows virus in Europe is still undetermined, but one of the purposes of this article is to suggest that there is a range of viruses, not all of them closely related to one another, causing yellowing symptoms in beet.

Beet yellows virus in the field

The disease now known to be caused by beet yellows virus (S.B.Y.), was first described in Europe as " Jaunisse ". Quanjer, in 1934, suspected it to be a virus disease. This was confirmed by Van Schreven (1936), and Roland (1936), who showed that it was transmitted by the green peach aphid, *Myzus persicae* and the black bean aphid, *Aphis fabae*. It was first identified in England in 1938 in plants from a small field experiment at Rothamsted (Watson, 1940). In the same year the virus was obtained from the Rothamsted and Woburn farms, and from other parts of England. There is no doubt that at this time it was common throughout the sugar beet growing districts of England. It had been described by Petherbridge and Stirrup (1935) under the name of " crackly yellows " and attributed by them to physiological causes.

Aphis fabae is usually much more numerous than *Myzus persicae* in sugar beet root crops and it was at first thought that this aphid was mainly responsible for spreading beet yellows virus (Watson, 1942), but field observations started in 1940, soon showed *A. fabae* to be of little importance compared with *M. persicae* (Watson, and Hull, 1946 ; Watson, Hull, Blencowe and Hamlyn, 1951).

Field experiments made between 1940 and 1943 demonstrated that serious losses could be caused by the disease, for early infection reduced sugar yield by more than half (Watson, Watson and Hull, 1946). Also the nutritional status of crops had little effect on proportional loss of potential yield, and no commercial varieties of sugar beet in present use, nor single lines derived from these varieties, showed promise of providing breeding material for the production of

tolerant or resistant strains (Hull and Watson, 1947). All these results showed that the disease was a potential threat to the sugar beet root crop, but it was not until after 1944 and 1945, when the first early and widespread outbreaks occurred, which were recognized as being caused by the virus, that serious attempts to find a means of controlling it were started.

Thousands of plants have been raised from seed set by infected beet plants, but no evidence has been obtained that S.B.Y. virus is transmitted through the seed. Attention was therefore concentrated on finding the sources from which the virus is introduced into the initially healthy root crop by the aphids. It was already known to be more prevalent in areas where beet and mangold seed crops are grown intensively than in other areas. These seed crops are raised in late summer as " stecklings ", and remain in the ground until they are planted out as seed plants, usually in the following early spring. They become infected in the steckling stage by aphids migrating from the root crops, and the virus remains in them through the winter, after the root crops have been harvested. Present control measures are mainly directed towards maintaining healthy seed crops. Stecklings are raised in isolation in areas where other chenopodiaceaous crops are not intensively grown, and transported to the seed-growing areas before planting out. These, and other methods that prevent the stecklings from becoming infected have been successful in producing healthy seed-crops, which give a heavier yield of seed than those from stecklings raised in conditions where they become infected (Hull, Rothamsted Reports, 1950, 1951). How far they will succeed in controlling the disease in the root crop as well, depends on how far the seed crops are the dominant sources of overwintering infection. Other sources, are clamped mangolds (Broadbent, Cornford, Hull and Tinsley, 1946), overwintering horticultural crops such as spinach and spinach beet, and *Beta maritima* in coastal areas, but their importance is uncertain. Recent examination of field data collected between 1943 and 1948 has shown that a high proportion of the variance in percentage infection between fields can be accounted for merely by variation in numbers of winged *M. persicae* visiting the crop (Watson and Healy, in preparation).

Transmission

Glasshouse studies with *M. persicae* and *A. fabae* as vectors (Watson, 1940, 1946), showed that beet yellows is a persistent virus. This means that the vectors do not become infective immediately they start to feed on infected plants, and they retain the ability to cause infection for hours or days after starting to feed on healthy plants. Persistent viruses are usually not transmitted by sap-inoculation, or are transmitted with difficulty, and this is true of beet yellows virus. For some years it could be transmitted only by aphids, but methods were later found by which it could be transmitted mechanically (p. 115).

M. persicae needs to feed for about six hours on infected plants before becoming fully infective, and for about six hours on healthy plants before they can cause all the infections of which they are capable. These times vary considerably, and some infections can

be caused with much shorter feeding times. Longer feeding times than six hours do not greatly increase their efficiency, though there is often a slow rise up to about 20 hours.

With some persistent viruses there is an appreciable period, after the vector is removed from the infected plant and placed on the healthy one, during which it cannot cause infection. This phenomenon is not exhibited by beet yellows virus, for some insects can transmit after only 15 minutes on the infected and 15 minutes on the healthy plants, and either period can be reduced to seven minutes if the other is more prolonged (Watson, 1940).

M. persicae may remain infective while feeding on healthy plants for at least three days after leaving the infected plants. The ability to infect is also retained through prolonged periods of fasting, though infectivity is lost rather rapidly during the first few hours. These properties contribute greatly to the widespread distribution of beet yellows virus in the field, for a single infective *M. persicae* can infect several plants, even after a prolonged migration flight.

Symptoms of beet yellows virus

Under glass, the first symptoms of infection in seedling beet appear within 7 to 10 days. The tissues immediately above the veins on the distal portions of the developing leaves usually become yellowed; the yellowed cells are at first raised above the leaf surface, but very soon they collapse and become necrotic. This "etch" symptom, so-called because of the fretted appearance of the tissues above the veins, forms a net-like pattern which spreads towards the base of the leaf. At a slightly later stage the etched leaves become generally yellow; after two or three weeks, the etch symptoms change to a generalized necrosis, and do not re-appear on leaves which develop subsequently. From this time onwards the developing leaves are green and healthy looking, but when almost fully expanded their tips become yellow and the yellowing spreads downwards over the whole leaf, tending to avoid the areas immediately around the veins. In the field affected leaves are bright golden colour, sometimes with scarlet spots or freckles; they become thickened and brittle, giving rise to the term "crackly yellows" by which the disease was first known in England.

This is a description of symptoms caused by the beet yellows virus which was isolated at Rothamsted in 1938. This isolate has been maintained in the glasshouse up to the present time, and has shown no appreciable modification of symptoms, or behaviour in relation to aphids. However, it was realized, even in 1938, that not all isolates from the field gave exactly the same symptoms. The general type of yellowing, and development was the same, but apparently most isolates at the time did not give the etch symptom (Watson, 1940). The older leaves merely became yellowed and the younger leaves were symptomless. In 1939 infected leaves were obtained from Professor Quanjer at Wageningen, to compare the English and continental yellowing viruses. The disease isolated from these leaves was of the mild type, free from the etch symptom. Vector relationships of the mild viruses resembled those of the severe virus, but the mild viruses were more difficult to transmit, and the symptoms were more difficult to observe, so they were

discarded. It was assumed that they were " mild strains " of the type virus.

Serology

An antiserum, made by injecting rabbits with sap from infected plants, was prepared against beet yellows virus in 1942 (Kleckowski and Watson, 1944), and some physical properties of the virus were determined. The activity of the antigen was destroyed by heating for 10 minutes at 50°C, and by keeping for two or three days at room temperature. It was unaffected by pH changes between 5 and 9, and could be reversibly precipitated by addition of ammonium sulphate to the clarified sap.

Sap taken from plants naturally infected in the field gave specific precipitates to this antiserum, and it was later found that sap from plants naturally infected in European countries also gave positive precipitin tests with it, and our virus with antisera prepared in Holland and Sweden.

The antiserum was of value for field diagnosis, but the results were not always clear-cut. Sometimes sap from old plants, late in the season, failed to precipitate with the antiserum in the usual way because they contained substances which inhibited specific precipitation except with very high concentrations of the antiserum. Aphid transmission tests from these plants usually showed that the virus was present.

Sometimes both tests failed, and it was assumed, with reservations, that the yellowing of the leaves was not caused by virus. But later results show that some of these leaves could have contained mild yellowing diseases which do not give positive precipitin tests with beet yellows antiserum, and which give symptoms that are difficult to identify, because most of these tests were done in the autumn, when light conditions are not very good. On the other hand the existence of apparent " mild strains " was known, and attempts had been made to re-isolate them so as to compare their effect on yield with that of beet yellows virus, but had been unsuccessful.

It is possible that the mild viruses were really absent from the English sugar beet crops at this time for the tremendous spread of viruses which occurred in them in 1944 and 1945 could have caused the mild viruses to be " swamped " by the more virulent beet yellows virus. Thus the composition of the yellowing diseases in the English sugar beet crops may have changed. This is also suggested by the fact that saps from field infected plants now give much greater precipitin titres than they did in earlier years.

The effect of concentration of inoculum on symptoms of beet yellows virus

Isolates which appeared to be mild forms of beet yellows virus were obtained from the field, and on several occasions were propagated in the glasshouse, to provide material for field experiments in the following year, but always, during the winter when sub-inoculations could not be made continuously, they reverted to the ordinary beet yellows type, showing the characteristic etch symptom.

Unstable " mild strains ", were also isolated from the type virus. The plants in any particular batch of inoculations show considerable

variation in symptoms, and it is possible, by repeated selection from the most mildly infected plants to produce " strains " from which the etch symptom is almost eliminated. However, these " strains " also could only be maintained so long as the transfers were made continuously. During the winter the distinctions between the mild isolates and the type virus disappeared.

It was thought that these so-called " strain " differences might be purely quantitative, that a plant with weak symptoms contained little virus, and that transmissions from it would give weakly infected plants, only so long as they were made sufficiently frequently to prevent the virus from building up to a " normal " level, i.e. that which provoked " normal " beet yellows virus symptoms. This was supported by the fact that saps from the mildly infected plants gave low precipitation titres.

A way of testing the effect of very small doses of virus compared with larger ones, was to vary the number of aphids used for transmission. With most other viruses this does not affect the final symptoms ; small or large doses of inoculum, whether applied mechanically or by means of aphids, give rise to identical symptoms, though the development time may vary. With beet yellows virus varying the number of aphids did cause variation in symptoms. When 1, 5 and 10 aphids were used to transmit the virus to groups of 25 plants in 4 replications (total of 100 plants per treatment), the total number of plants which became infected were : 34, 75, and 94 respectively. These figures fit well with the hypothesis that the infections are local and independent (Watson, 1936), the chances of a plant becoming infected being no greater than the chance that a single aphid in any group will give rise to infection. However, the numbers of plants showing severe symptoms with definite etch, were 4, 31, 51, for the 1, 5 and 10 aphid groups. The increase in severe symptoms with aphid number was thus greater than would be expected if the mild and severe symptoms were caused by infection with strains of different virulence, but seemed to depend rather on the quantity of virus initially introduced into the plants.

Other yellowing diseases of sugar beet

In 1946 an aphid transmissible yellowing disease was isolated from a single " breeder's pure line " of sugar beet (Family 41), bred by B. Crombie of the Eire Sugar Corporation. This virus was remarkable in being readily transmissible through the seed of Family 41, and it was this property which led to its discovery, for had it not appeared in a large proportion of the progeny from a single " mother beet ", it would probably have escaped notice. The Family 41 disease was investigated in Eire by Clinch and Loughnane (1948), who found that two yellowing diseases of sugar beet were common in Eire. One was a mild yellowing disease which did not give the etch symptoms, and the other was a severe yellowing disease which seemed to be the same as the beet yellows virus in England, but differed from it in that the etch symptom persisted throughout the life of the plant, nor merely for the first two or three weeks after inoculation. The symptoms and behaviour of the mild yellowing strain of beet yellows virus seemed to be indistinguishable from those of the yellowing disease of Family 41, so Clinch and Loughnane

concluded that they were the same, and that both were strains of beet yellows virus. Their explanation of the seed transmission in Family 41 was that this strain of sugar beet had developed a genetical abnormality which permitted the passage of the virus into the seed.

They made the interesting observation that neither 41 yellows nor the " mild strain " of beet yellows virus could protect a plant against subsequent inoculation with the " severe strain ". A positive cross immunity test is usually accepted as indicative of strain relationships between plant viruses, but Clinch and Loughnane doubted its validity as a test for relationship between aphid transmitted viruses of the beet yellows type, which were thought to be confined to the phloem. At this time beet yellows virus was not known to be sap-transmissible.

Work done at Rothamsted on the yellowing disease of Family 41, and the mild virus (Irish Mild Yellows, I.M.S.), isolated from ordinary sugar beet crops in Eire, has confirmed that neither willl protect against S.B.Y. virus. It was also found that saps from 41 Yellows and I.M.S. infected plants, whether taken from the glasshouse or grown out of doors, did not precipitate specifically with beet yellows antiserum. Failure to precipitate would be caused if the mild yellowing viruses did not contain the antigen against which beet yellows antiserum is formed, or if the antigen were in very low concentration relative to the amount in beet yellows virus. If it is merely a question of concentration, special techniques might be used to increase the concentration of virus in the extracted sap and induce it to precipitate specifically with the antiserum, but so far this has not been possible, and the evidence, at present, is that the viruses are not serologically related. I.M.S. virus appears to be quite stable and has been maintained in the glasshouse for several years.

Although symptoms of 41 yellows are very similar to those of Irish mild yellows when the plants are grown out of doors, in glasshouse conditions they do not seem to be identical. The disease caused by I.M.S. virus resembles the mild yellowing diseases isolated from fields in England in 1938, and also the unstable mild strains isolated from beet yellows virus by selection. The main difference between them and beet yellows virus is that there is no etch symptom. With 41 yellows the symptoms of the virus when transmitted to healthy seedlings are much weaker and more ephemeral. Sometimes only one leaf becomes yellowed or shows yellowed patches, and recovery may appear to be complete within a few days. If the plants are planted out of doors the yellowing symptoms return, and the seed always contains a high proportion (sometimes over 40 per cent), of infected progeny. The symptoms in the progeny are very variable. If they appear soon after germination they may cause stunting, distortion or death of the plant. If they develop when the plant is a few weeks old, they may look very like Irish mild yellows. The 41 yellows virus is also more difficult to transmit by aphids than Irish mild yellows. Using 10 aphids per plant only about 10 per cent of plants showed visible symptoms, compared with about 80 per cent for I.M.S. virus. With very large numbers of aphids or constant movement between infector and test plants

(Clinch and Loughnane, 1948), this kind of difference largely disappears.

The virus of 41 yellows was found to be transmissible through the seed of other varieties than Family 41. These were Kleinwanzleben E variety, and some breeders' pure lines derived from Hilleshog variety. Therefore seed transmission is not confined to Family 41, and the suggestion that a genetical mutation in the plant is the cause of seed transmission is untenable. Work is still in progress to find whether I.M.S. virus is seed transmissible, but it seems unlikely, because the disease is common in Eire, and probably many seed stocks would have become infected if it were normally seed transmitted.

On present evidence the three viruses seem to be distinguishable from each other by serological heterogeneity, by the property of being seed transmitted, and by the symptoms produced in certain conditions, and it seems unlikely that they are the same virus, or even very closely related strains.

The existence of stable mild yellowing diseases suggested an explanation for the behaviour of the disease discovered in Australia. This also resembled beet yellows virus in the field, and it was transmissible by aphids to spinach, but apparently could not be reintroduced into sugar beet under glass. It also failed to precipitate specifically with beet yellows antiserum. These characters suggest that it might be another mild yellowing disease such as Irish mild yellows.

Sap transmission of beet yellows virus

In 1941 Kassanis showed that beet yellows virus could be transmitted by sap inoculation to sugar beet plants. The necessary conditions were that the test plants should be kept for at least one or two days in the dark, that the inoculum should be obtained from severely affected plants showing good etch symptoms, and that the inoculation should be made with an abrasive. In these conditions rubbing a mature healthy leaf with infected sap caused the appearance of numerous dark coloured necrotic lesions. About 25 per cent of the plants became systemically infected, showing both etch and yellowing symptoms, and sap from them precipitated specifically with beet yellows antiserum. When similar inoculations were made with beet yellows virus into the leaves of Irish mild yellows infected plants, lesions appeared just as quickly as in healthy plants, and appeared to be even more numerous. This seemed to show conclusively that the failure to show immunological relationships between these two viruses was not because they were confined to the phloem.

The necrotic strain of beet yellows virus

The statement made by Clinch and Loughnane that etch symptoms persisted in their beet yellows infected plants also led to further investigation of the symptoms of this virus. It might appear to be a rather unimportant difference, but we had paid so much attention to following the course of the etch symptom, and failed so often either to eliminate or materially to increase it in any stable isolate, that it seemed to be of considerable interest. We had

already observed that some plants in the field retained their etch symptoms throughout the growing season (Hale *et al*, 1946), and we had attributed this, vaguely, to some genetical attribute of individual plants. Our beet yellows virus was not collected from such a plant, but from one showing typical " crackly-yellows " from which any early etch symptoms had presumably disappeared. Therefore new isolates were made from the field, from old plants in which etch symptoms had persisted. These isolates gave rise to infected plants in which the etch symptom persisted throughout life, even through the winter months when the yellowing symptom had completely disappeared. Saps from these plants precipitated with antisera made against S.B.Y. infected sap, and gave higher titres than saps from S.B.Y. infected plants.

Cross inoculation tests were made between this virus and the S.B.Y. virus by the expedient of waiting until the etch symptoms had almost disappeared from the S.B.Y. plants, and then inoculating these plants, and healthy plants of the same age, with the new isolate (S.B.Y.N.). The results were quite clear-cut, for the S.B.Y. plants failed to develop any further etch symptoms, but the healthy plants became infected with the new virus, and produced etch symptoms plentifully on their developing leaves, later exhibiting typical S.B.Y. symptoms of the persistent etch type. This experiment showed that one sugar beet virus can protect against another. With other viruses this is regarded as evidence of relationship. The fact that protection can be established means that failure to exhibit it also suggests lack of relationship. Therefore I.M.S. virus is more distantly related to S.B.Y. virus than is S.B.Y.N., as its failure to give a positive precipitin test with S.B.Y. antiserum also indicates.

S.B.Y.N. has proved stable, and is useful for experimental work because of its ability to cause easily recognizable symptoms in the glasshouse in winter.

Yellow-net virus

In 1949 Sylvester, in California, described another aphid transmitted virus of sugar beet, which was persistent in the vectors *M. persicae* and *A. fabae*, and was apparently not sap-transmissible. In its general properties it thus resembled beet yellows virus, but its symptoms, superficially, did not. The disease caused a striking yellow vein-banding symptom, which never became necrotic and which affected all the veins of the leaves, sometimes over the whole plant. The net-like pattern of the anastomosing yellowed veins suggested the name of Yellow-net virus.

In 1950 Dr. Hull isolated a virus whose symptoms and properties appear to be identical with yellow-net, from a plant found in a field in Lincolnshire. This virus is less readily transmitted by *M. persicae* than is beet yellows virus. The aphids require longer feeding times on infected and healthy plants to develop optimum infectivity, and probably they remain infective for a longer time, though this has not yet been measured exactly.

The symptoms are rather erratic in their time of appearance ; sometimes they are obvious within 10-14 days of inoculation and sometimes they appear at intervals of three or four weeks. There

is little difference in symptoms whether the plants are grown in or out of the glasshouse, and many plants retain the symptom fully, throughout the winter.

In transmission tests some plants failed to produce yellow-net symptoms, but did produce symptoms which were not distinguishable, either in or out of the glasshouse, from those of I.M.S. virus. This virus, which we call the yellow-net mild strain, is easily isolated from the yellow-net complex, for it seems to be more readily transmitted by the aphids, and many transmission tests which fail to transfer yellow-net are highly successful with the mild strain. Subcultures can be made repeatedly from these plants without the yellow-net virus re-appearing. The yellow-net mild strain appears to be quite uniform and stable. So far, yellow-net has not been isolated free from the mild strain. Whether there is an obligate association between the two viruses, or whether the failure is due to the greater ease with which the mild strain is transmitted, requires more work to establish, but the character and properties of the two viruses are sufficiently like those of beet yellows virus for them to be included in the same group. In fact there seem to be some points of resemblance between the yellow-net virus and the etch component of S.B.Y. virus. Both affect the tissues above the veins causing chlorosis, neither are greatly affected by glasshouse conditions compared with outdoor conditions, and both persist throughout the winter. They are both associated with mild yellowing viruses which can exist independently, but neither has been isolated free from these yellowing viruses so far.

Neither the yellow-net complex nor the yellow-net mild strain virus has given positive precipitin tests with beet yellows antiserum.

The effects of light and carbohydrate supply on beet yellowing viruses

One aspect of the work with the beet yellowing viruses which has continually caused anomalous and contradictory results, was the apparent dependence of the appearance of the yellowing symptoms on conditions of growth. The factor believed to be mainly concerned is light intensity.

Beet yellows virus has been associated with abnormalities in carbohydrate metabolism and translocation ever since it was first described by Quanjer, who observed that the yellowed leaves contained unusually large quantities of starch. He attributed this accumulation to degeneration of the phloem which was thought to interfere with translocation, but Klinkenberg, 1948, showed that phloem symptoms are not necessarily associated with symptoms of beet yellows virus, and when they do occur, it is after most of the carbohydrate has accumulated.

Watson and Watson, 1951, showed that, though starch, sucrose and hexose all accumulated in the yellowed leaves of plants infected with beet yellows virus, translocation was not obstructed but was the same for healthy and diseased leaves. They showed also that carbohydrate is not increased in the young, green leaves of infected plants, but only in the older ones. This is shown by the following abstract from the data :—

Total carbohydrate as per cent dry matter content

	Old leaves		Young leaves	
	Healthy	Infected	Healthy	Infected
Per cent carbohydrate ...	8·4	18·7	12·5	12·0

These results suggested that the yellowing depended in some way on the accumulation of carbohydrate caused by the virus, and that where this did not naturally occur, as in the young leaves, or was prevented by lack of light as in shade or winter conditions, yellowing also did not occur.

Experiments were made to compare the effects of light and shade on symptom production, and also to see whether artificially increasing the carbohydrate content of the leaves would intensify the yellowing symptoms. This was done by spraying the leaves of infected and healthy plants daily with a 10 per cent solution of sucrose, in ordinary glasshouse conditions in the spring, and treating other plants at the same time in muslin cages placed in the glasshouse, which reduced the light intensity to about half.

The concentration of sucrose and starch in leaves of healthy and infected plants was increased by sugar spraying. Yellowing symptoms were increased on infected plants, but not produced on healthy ones. The increase of yellowing symptoms was more conspicuous in plants which were not shaded than in those which were. The shaded plants produced scarcely any yellowing, and the improvement produced by spraying was small and somewhat irregular. The etch symptoms were less affected both by sugar spraying and by shading than were the yellowing symptoms.

Serological tests on saps from the differently treated plants were rather unsatisfactory, because the antiserum then available was poor, and the virus titres were very low, at best only 1/32. The virus was detected in old (yellowed) and young leaves of all infected plants. Titres were higher in the unshaded plants, and in these plants, were higher in the yellowed than in the young leaves. The best titres were obtained for the yellowed leaves which received sugar, but whether this indicated a real increase caused by sugar is uncertain. In shade conditions the young leaves gave a slightly higher titre than the old (unyellowed) leaves, and again sugar caused a rather doubtful increase.

These results suggest that, though beet yellows virus is the cause of the yellowing symptom, it cannot produce that symptom when the carbohydrate content of the leaves is low. Thus, on this hypothesis, yellowing does not occur in the young leaves, because in them the carbohydrate of infected plants is not in excess of the normal carbohydrate content of the leaf, as judged by the condition of the healthy ones. Where there is great excess of carbohydrate the yellowing symptoms are severe ; in shade conditions when carbon assimilation is insufficient to cause excessive accumulation of starch and sugars, symptoms are slight or absent.

If this applies to all the viruses which cause typical yellowing symptoms in sugar beet, as their general behaviour suggests, it explains why plants grown in comparatively shady conditions in glasshouses produce poor symptoms, whereas the same plants placed out of doors have good visible symptoms. Unfortunately

growing the plants out of doors is not a possible solution to the problem of symptom failure in experiments, because natural infection with other yellowing diseases cannot be controlled. However it is usually possible to ensure that critical experiments are done in as good light conditions as possible, and with most of the yellowing viruses, it is possible to detect symptoms in glasshouse conditions, if it is ensured that the plants grow well enough for the yellowing to be distinguished from nutrient deficiency, wilting, and so on.

The best results are obtained, in this country, between April and the end of July, but even then symptom production may be poor if the houses are too frequently shaded by heavy blinds. Good symptoms are not produced in most glasshouses if the plants are grown in cages to protect them from aphid attack.

The existence of these mild yellowing virus diseases of sugar beet, together with the extreme effect of shading on the symptoms, the ephemeral nature of the etch symptom in some S.B.Y. strains, and the fact that symptoms can be affected by varying the dose of inoculum during transmission, make it difficult to relate the results of experiments made under varying conditions. More work will be needed before the relationships between some of the recently identified yellowing diseases of sugar beet and those previously described are fully understood.

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REVIEW OF WORK ON MANGANESE OXIDATION IN HIGHER PLANTS

By P. J. G. Mann

The work to be reviewed was undertaken in the Biochemistry Department at Rothamsted in 1948 with the object of investigating whether manganese undergoes a cycle of oxidation and reduction in higher plants. The work developed from the observation that with water extracts of certain plant roots in presence of pyrophosphate at pH 7 a pink colour was obtained within a few minutes of adding manganous sulphate and hydrogen peroxide; this suggested that manganipyrophosphate had been formed. Except in strongly acid solutions manganic ions are unstable and dismute to manganous ion and hydrated manganese dioxide :—

$$2\,Mn^{+++} + 2H_2O \longrightarrow Mn^{++} + MnO_2 + 4H^+ \quad \ldots \quad (1)$$

Some complexions of manganic manganese are more stable. Thus manganipyrophosphate is stable up to pH 9 but dismutes at more alkaline reactions. By making use of this dismutation Kenten and Mann (1949) isolated manganese dioxide from large-scale reaction mixtures of plant extract, manganous sulphate and hydrogen peroxide and thus proved that the colour reactions obtained were indeed due to the formation of manganipyrophosphate. The manganese dioxide isolated in such experiments was equivalent to only 25-40 per cent of the hydrogen peroxide added. A manometric study of the reaction showed that these low yields were due to the fact that manganipyrophosphate reacts stoicheiometrically with hydrogen peroxide under the experimental conditions. The oxidation therefore causes oxygen evolution and the reactions taking place in the pyrophosphate media may be represented by the equations :—

$$2MnO + H_2O_2 \longrightarrow Mn_2O_3 + H_2O \quad \ldots \quad \ldots \quad (2)$$

$$Mn_2O_3 + H_2O_2 \longrightarrow 2MnO + H_2O + O_2 \quad \ldots \quad (3)$$

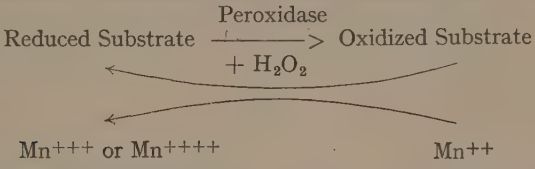
The accumulation of manganipyrophosphate therefore depends on reaction (2) being more rapid than reaction (3). No accumulation of manganese oxidation product could be demonstrated in orthophosphate media. Here a stable manganic complex cannot be formed and oxidation would result in the formation of manganese dioxide either directly or through the dismutation of an unstable manganic complex. Manganese dioxide does not accumulate in the orthophosphate media because the rate of its reduction by hydrogen peroxide (4) is as rapid as its formation :—

$$MnO_2 + H_2O_2 \longrightarrow MnO + H_2O + O_2 \quad \ldots \quad (4)$$

Under these conditions the rate of decomposition of the hydrogen peroxide is a measure of the rate of manganese oxidation. In manometric experiments it was shown that the addition of as little as 1 μg Mn^{++}/ml extract increased the rate of decomposition of hydrogen peroxide by plant extracts. Indirect evidence was thus obtained that manganese oxidation by the system proceeded readily at physiological concentrations of Mn^{++}.

Analysis of the oxidizing system showed that it consisted of a thermolabile and a thermostable factor in addition to hydrogen peroxide. Evidence was obtained that the thermolabile factor is

the enzyme peroxidase and the thermostable factor a peroxidase substrate. It was suggested, as a working hypothesis, that intermediate products of the oxidation of certain peroxidase substrates can bring about manganese oxidation according to the scheme below which involves the substrate in a cycle of oxidation and reduction.



The concentrations of hydrogen peroxide used in the preceding experiments were necessarily high compared with those likely to be present *in vivo*. It was suggested that *in vivo* the manganese oxidation product would react preferentially with plant metabolites other than hydrogen peroxide thus involving the manganese in an oxidation-reduction cycle which could be responsible for its known effect on plant respiration.

In subsequent work Kenten and Mann (1950) established the fact that peroxidase in presence of certain of its substrates, catalyses the oxidation of Mn^{++}. The reaction mixtures used in this work were similar to those previously described with the exception that the plant extracts were replaced by partially purified peroxidase preparations together with peroxidase substrates such as phenol or p-cresol. Manganese dioxide was isolated from large-scale reaction mixtures. In manometric experiments systems active in manganese oxidation were produced by the use of a few μg of peroxidase preparation and phenolic substrate. The catalytic activity of the phenolic substrates in the oxidation was illustrated by the fact that in one experiment the addition of 1 μg p-cresol to the system led to an accumulation of manganipyrophosphate equivalent to 605 μg Mn_2O_3. Probably the most important results of the manometric work were those obtained in a study of the effect of variation in the hydrogen peroxide concentration. Under the conditions used, the accumulated manganipyrophosphate, calculated as a percentage of that theoretically possible, increased with decreasing concentration of hydrogen peroxide from 30 per cent at 0·0066 M. hydrogen peroxide to 80 per cent at 0·0017 M. which was the lowest concentration practicable with the technique used. This result supported the suggestion previously made that with sufficiently low hydrogen peroxide concentrations all the manganese oxidation product would be available for the oxidation of plant metabolites other than hydrogen peroxide.

The possibility that the oxidizing capabilities of peroxidase systems towards inorganic compounds are not confined to compounds of manganese was investigated by Kenten and Mann (1951). The results of this work showed that peroxidase in presence of suitable phenolic substrates catalyses the oxidation of ferrocyanide by hydrogen peroxide and possibly that of molybdates, vanadates and tungstates, though in the latter cases direct proof of the oxidation was not obtained. It was found that under certain conditions the rate of oxidation of Mn^{++} by peroxidase systems is markedly

increased by catalytic concentrations of these compounds. Thus a clear effect of ammonium molybdate was obtained at a concentration of 10^{-6} M. (2·4 μg Mo/3ml). This was attributed to catalysis by peroxidase systems, of the oxidation of molybdates, tungstates and vanadates by hydrogen peroxide to the corresponding peroxy compounds according to the general equation :—

$$X{\cdot}OH + H_2O_2 \rightleftharpoons X{\cdot}O{\cdot}OH + H_2O \quad \ldots \quad (5)$$

It was shown that these peroxy compounds rapidly oxidise Mn^{++}.

In the work so far described with plant extracts or peroxidase preparations, the oxidations studied were dependent on added hydrogen peroxide. Such oxidations can take place in plants *in vivo* only if hydrogen peroxide is formed by the plant tissues. The work of Kenten and Mann (1952a) showed that Mn^{++} is oxidized by plant extracts in absence of added hydrogen peroxide and that such oxidation forms a useful test for the presence in the extracts of enzyme systems producing hydrogen peroxide. The blue coloration obtained when benzidine and hydrogen peroxide are added to most plant and animal tissues is known to be due to the catalysis by peroxidase, or by the peroxidatic action of haem or haematin derivatives, of the oxidation of benzidine by hydrogen peroxide. Therefore a blue coloration obtained with tissue and benzidine in the absence of added hydrogen peroxide suggests the formation of hydrogen peroxide by the tissue. Using this test for the production of hydrogen peroxide by plant extracts Kenten and Mann (1952a) obtained negative or only weakly positive results. But extracts of many plants gave positive benzidine tests after incubation with Mn^{++} and pyrophosphate at pH 7. Evidence was obtained that this was due to oxidation of the Mn^{++} and accumulation of manganipyrophosphate which readily oxidizes benzidine. The manganese oxidation was shown to be dependent on the formation of hydrogen peroxide by the plant extracts. Hydrogen peroxide cannot accumulate to any extent in the extracts owing to their strong catalatic activity.

In attempts to identify the enzyme systems producing hydrogen peroxide it was shown that pea seedling extracts (*Pisum sativum* L.) oxidize both mono- and di-amines according to the general equation :

$$R{\cdot}CH_2{\cdot}NH_2 + O_2 + H_2O \longrightarrow R{\cdot}CHO + H_2O_2 + NH_3 \quad \ldots \quad (6)$$

Some evidence was also obtained of the presence of an aldehyde oxidase catalysing the oxidation of phenylacetaldehyde with hydrogen peroxide formation. It seems of particular interest that tryptamine is among the amines attacked by the amine oxidase in view of the evidence that tryptamine can function as a precursor of indoleacetic acid in the plant. The action of the amine oxidase on tryptamine presumably results in the formation of indoleacetaldehyde. It was suggested that indoleacetaldehyde is a substrate of the aldehyde oxidase present in the extracts and that indoleacetic acid could be formed from tryptamine by the action of the amine oxidase followed by that of the aldehyde oxidase.

The oxidation of added Mn^{++} by plant extracts in absence of added hydrogen peroxide was attributed by Kenten and Mann (1952a) to the presence in the extracts of enzyme systems producing hydrogen peroxide. In subsequent work Kenten and Mann (1952b) working with partially purified enzyme preparations demonstrated

the oxidation of Mn^{++} by enzyme systems producing hydrogen peroxide coupled with peroxidase. The enzyme systems used to provide hydrogen peroxide were the D-amino-acid oxidase and xanthine oxidase from animal sources and the plant amine oxidase systems already described. The reactions catalysed by these enzymes may be represented by the general equation :—

$$RH_2 + O_2 \longrightarrow R + H_2O_2 \quad \ldots \quad \ldots \quad (7)$$

If the hydrogen peroxide formed is decomposed by catalase according to the equation :—

$$H_2O_2 \longrightarrow \tfrac{1}{2}O_2 + H_2O \quad \ldots \quad \ldots \quad (8)$$

the apparent oxygen uptake is halved and the net reaction is :—

$$RH_2 + \tfrac{1}{2}O_2 \longrightarrow R + H_2O \quad \ldots \quad \ldots \quad (9)$$

It is well known that the hydrogen peroxide produced by these enzyme systems may be used for secondary or coupled oxidations catalysed by peroxidase. Where catalase is present such coupled oxidations cause increases in the apparent oxygen uptake which may reach 100 per cent if all the hydrogen peroxide is used in the coupled oxidation rather than decomposed by catalase. In manometric experiments with these enzyme systems in both pyrophosphate and orthophosphate buffers it was shown that, in presence of catalase, the addition of peroxidase and manganous sulphate together with catalytic amounts of p-cresol caused a doubling of the oxygen uptake of the primary reaction suggesting that all the hydrogen peroxide was used for manganese oxidation. This was confirmed by the finding that the manganese oxidation products which accumulated were equivalent to the hydrogen peroxide produced in the primary reactions. Manganese oxidation was also observed in systems composed of the plant enzyme α-hydroxyacid oxidase and its substrates, lactic or glycollic acids, with peroxidase. Proof was thus obtained that hydrogen peroxide is formed in oxidations catalysed by α-hydroxyacid oxidase. This has since been confirmed by more conventional methods (Kenten and Mann, 1952c).

In the preceding experiments, designed to demonstrate quantitative accumulation of manganese oxidation products, Mn^{++} was added in amounts more than equivalent to the hydrogen peroxide formed by the primary enzyme system. It was shown that Mn^{++} when present in low concentrations was also oxidized by adding oxalate to the system which reduced the manganese oxidation product as fast as it was formed and thus allowed the Mn^{++} to undergo a cycle of oxidation and reduction. The oxidation of these small amounts of Mn^{++} with accumulation of the oxidation product produced little increase in the oxygen uptake. Where oxalate was present in addition to Mn^{++}, however, large increases in oxygen uptake were observed due to the manganese oxidation-reduction cycle.

In this attempt to reconstruct with purified enzyme preparations the type of systems which causes manganese oxidation in plant extracts the significance of the results lies not merely in the fact that manganese oxidation was observed but also that the oxidation product accumulated quantitatively. In previous results with added hydrogen peroxide the accumulation of manganipyrophosphate was not quantitative and no accumulation could be demonstrated in orthophosphate owing to reduction of the manganese

dioxide by hydrogen peroxide (equations 3 and 4). Provided the hydrogen peroxide concentration is sufficiently low this reduction is negligible and all the oxidation product would be available in the plant for the oxidation of metabolites other than hydrogen peroxide as suggested by Kenten and Mann (1949). Under such conditions the Mn^{++} would undergo, in the plant, a cycle of oxidation and reduction as demonstrated *in vitro* in the experiments with oxalate as reductant.

The results obtained may throw light not only on the physiological action of manganese but also on that of peroxidase. Peroxidase is widely distributed in higher plants but its functions are unknown. It has not been shown to catalyse the oxidation of any compound recognized as an intermediate in the main pathways of metabolism. Since peroxidase catalyses the oxidation of Mn^{++} the range of compounds which peroxidase systems can oxidize will be extended by addition of Mn^{++} to include those compounds capable of oxidation by the manganese oxidation product. Thus, in work as yet unpublished, it has been shown that in presence but not in absence of Mn^{++} peroxidase systems oxidize not only oxalate but also oxaloacetate, ketomalonate and dihydroxytartrate.

Manganese oxidation has not yet been demonstrated in the plant *in vivo* under normal conditions of manganese supply. In preliminary experiments with plants grown in water culture with high manganese concentrations evidence has been obtained of the accumulation of manganese oxidation products in the tissues. This can generally be shown in the pea plant (*Pisum sativum* L.) with concentrations of Mn^{++} of the order of 50 p.p.m. in the culture solution. It has already been shown that the oxidation takes place *in vitro* with physiological concentrations of Mn^{++}. At such concentrations of Mn^{++} *in vivo* it is possible that the oxidation product is reduced by plant metabolites as fast as it is formed and that only under conditions of manganese toxicity is the rate of oxidation faster than the rate of reduction. This suggests the possibility that the symptoms of manganese toxicity may be due, at least in part, to the deposition of higher oxides of manganese in the plant tissues.

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HOW FAR DO INSECTS TRAVEL?

By C. B. Williams

A knowledge of the distances that either injurious or beneficial insects can move is of major importance to economic entomologists all over the world in planning either direct control, or measures for the prevention of outbreaks of insect pests or of insect-borne diseases.

Apart from accidental transport in cars, trains, ships and aeroplanes, which is a major problem in itself, movements of insects over longer or shorter distances can take place actively—by the action of the insects themselves, or passively—when they are carried away by the wind. The active movements may be just the normal flight of the insects wandering round their habitat, or may be definite flights over a long distance in a fixed direction. For the latter type of movement we use the term " migration ".

As the study of insect migration and insect drift has been one of the major investigations of the Department of Entomology at Rothamsted for many years, it may be of interest to summarize some of the results obtained, and to show how they have altered the outlook of the applied entomologists.

There is no doubt that 50 years ago, or less, there was little knowledge and much misunderstanding, particularly among the general public, about how long insects lived in their adult winged stage and how far they could move during that period.

To clear up the former point we may say that an adult life of less than a week is probably unusual in flying insects ; that most live two or three weeks ; that quite a number live several months ; and that a small number of species (including bees and ants) are known to live several years. In a life of even only a few weeks there are possibilities of movement much greater than that of the hypothetical May-fly which hatches in the evening and is dead before daybreak, and we now know that even in 24 hours the distances covered could be measured in miles rather than in yards.

In lectures on Agriculture at the University of Cambridge in 1910, one of the major reasons given for the rotation of crops was its value in preventing outbreaks of insect pests. There are undoubtedly some pests, particularly those in the soil, which have little power of movement ; and there are others, such as wireworms, with a larval stage lasting several years, in which a sudden break in continuity of food supply might possibly be injurious to the insect. But to imagine that the average insect pest would be seriously incommoded by having to move from one side of the hedge to another in order to find its next year's food supply is quite unjustified.

There are many good reasons for a rotation of crops in farming practice, but the value of the process as a method of avoiding insect pests has been greatly exaggerated.

It is perhaps interesting to note at this stage that Broadbalk field has, in the first 100 years of wheat growing, not yet suffered from any major disaster. So that the absence of rotation does not appear to be—by itself—a necessarily dangerous proceeding in the development of insect attack.

In a light trap that was worked by the Entomology Department on one of the fields at Rothamsted for four consecutive years 1933-1936, 240 different species of moths were captured. The total number of known species in the families of insects concerned is about 750 for the whole of the British Isles, so that in four years almost one-third of all the British species of moths had visited one spot in one field. Some of these may have bred within a few yards of the trap—some others, on the contrary (such as the Silver-Y Moth, *Plusia gamma*), may have migrated to the field from hundreds of miles away—but the majority had undoubtedly wandered accidentally to within the very limited sphere of danger round the traps from their natural habitats within perhaps a few miles of the trap.

Had the trap been a plant newly introduced to the area, then we must realize that in about four years perhaps one-third of the British moths would have come near enough to see whether or not it was suitable for food; and there is little doubt that most other groups of winged insects are capable of similar wanderings.

When we come to study the problem of movement in insects known to migrate, the distances covered rise from yards and miles, to tens or hundreds of miles, and occasionally even to a thousand or more.

Nearly every year our British population of Large Cabbage-White Butterflies (*Pieris brassicae* L.) is reinforced by considerable immigration from the Continent across the southern North Sea and the eastern half of the English Channel. Millions of butterflies cross without difficulty the 30 to 300 miles that separate us from France, Belgium, the Netherlands and Denmark. We have good reason to believe that before setting out to cross the North Sea, the butterflies had already in many cases flown from north Germany, from southern Scandinavia, or from islands in the Baltic (Williams, 1939).

An entomologist who studied the biology of this butterfly in England some years ago expressed an opinion that its death rate from parasites was so high that it was doubtful if it could long survive in Britain if it were not for the regular reinforcements which arrive from the Continent.

The Silver-Y Moth (*Plusia gamma* L.)—an irregular pest of peas, beans and many other field crops in England and Central Europe—does not survive the winter in any stage in these latitudes, but flies in from the Mediterranean area each spring in varying numbers. A big migration usually means a big outbreak and widespread damage—but the real source of the trouble is 400 miles or more from the area of damage if they have come from the northern shores of the Mediterranean, and more than twice that distance if their origin has been in North Africa.

In Egypt I have had experience with a case of an opposite kind. The Greasy Cutworm (*Agrotis ipsilon* L.) is a serious pest of grain in the autumn and winter months and occasionally attacks young cotton in the early spring. Money was at one time spent on a "control" measure which consisted of trapping, by means of a poison bait, large numbers of the adult moths particularly about April and May. It was then discovered that the insect was a

migrant and only a winter visitor to Egypt. Every spring all the moths left the country and, almost certainly, flew to Europe—hundreds of miles away. A failure to understand this aspect of their behaviour resulted in much wasted effort and expenditure.

In North America one of the major pests of cotton during the nineteenth century was the "Cotton Leaf Worm" (*Alabama argillacea* Hbn.). It appeared each summer in the cotton belt of North America, and several generations in rapid succession often did enormous damage. During the winter the insect could not be found in any stage of development in any part of the cotton belt, nor could any alternative foodplant to cotton be discovered. Just a hundred years ago it was first suggested that the moths were coming in each spring as immigrants from South or Central America. This is now known to be the correct interpretation, although the exact area of origin is still uncertain, but for at least 50 years the suggestion was thought to be a wild improbability owing to the great distance of movement required.

The Painted Lady butterfly (*Pyrameis cardui* L.), which is occasionally a serious pest of artichokes in France, but is mildly beneficial in the U.S.A. where it feeds chiefly on thistles, breeds during our winter in the arid areas on the edges of the Great North African Desert. From there it moves north each spring, first to the north coast of Africa, then across the Mediterranean and northwards across Europe. It reaches the latitude of the British Isles almost every year about June, and not infrequently wanders on still further to Iceland in the west and to beyond the Arctic Circle in Finland. The total distance covered may be nearly 2,000 miles.

The same butterfly in North America appears to have its winter quarters in Western Mexico (where there are arid conditions somewhat similar to North Africa) and to spread out each spring towards the north and north-east. In some years thousands of millions of insects are concerned in the flights, and they may spread over the greater part of the United States and southern Canada, even as far as the mouth of the St. Lawrence River and to Newfoundland. Altogether they may move nearly 3,000 miles from their starting point in Mexico.

There is no evidence of winter survival of Painted Lady butterflies anywhere in northern Europe or in the United States.

There is no need to stress the great distance that can be traversed by swarms of locusts. Some of the few individuals that have occasionally been captured in Britain have been shown (by statistical measurements) to have almost certainly come from populations in south-eastern Europe—a distance of well over a thousand miles. Locusts and Painted Lady butterflies have on several occasions been captured on board ships more than a thousand miles from land.

An unusual adaptation to migration came to my notice in East Africa, where a burrowing wasp (*Sphex aegyptiacus*), which is predaceous on locusts, was found to have developed a habit of migrating along with the swarms of its host—so that both pest and predator were moving over many miles of country deliberately and simultaneously.

Many species of dragonflies are capable also of flights to be measured in hundreds of miles. I have seen them myself more than

a hundred miles from water in the Egyptian desert, and—like the locusts and butterflies mentioned above—they have been recorded on ships at sea hundreds of miles from the nearest land, and hence from the nearest fresh water which is necessary to them for breeding.

Ladybirds in California are known to move from the coastal plains to the hills about 50 miles away every autumn for the purposes of hibernation, and to return back to the coast in the spring; and a somewhat similar habit is found in the American Bean Beetle (*Epilachna*), a relative of the ladybird which however lives on a vegetarian diet.

Turning now to the question of passive drifting of insects, this chiefly affects the smaller species with poor powers of flight which are easily carried away from the ground by winds and by convection currents. The insects mostly concerned are Aphidae (greenflies), small Diptera, small Hymenoptera, small beetles, with occasional Lacewings and other groups. They include many pests and transmitters of disease.

Small insects are often carried short distances of a hundred yards to a mile or so by winds quite near to the ground, but once they get away from the ground into the upper air they may be carried tens or even hundreds of miles before they come back to earth.

As early as 1913 entomologists in America had shown that the just hatched caterpillars of the Gipsy Moth (*Porthesia dispar*), which are covered with long hairs, are so buoyant in the air that they could be carried at least a mile by air currents near the ground. Two years later Collins (1915) showed that they could be carried up to at least 13 miles.

Experimental work with traps attached to aeroplanes was carried out between 1926 and 1931 in Louisiana, U.S.A., and the results (Glick, 1939) showed a total of nearly 25,000 insects caught at heights from 200-16,000 feet in a trap 1 foot square, in about 900 hours of flying during day hours. This is an average of about 30 insects per hour.

In about 100 hours flying at night time up to 5,000 feet, about 4,000 insects were caught.

The insects that were identified included about 700 different species belonging to 198 families and 18 different orders. There were also over 1,000 spiders and a small number of mites.

Included among the insects were over 50 wingless Thysanura and Collembola (one of the latter at 11,000 feet) and many wingless immature stages of Heteroptera, Homoptera, Orthoptera, Coleoptera, Lepidoptera and Diptera—also numbers of wingless ants.

In Britain Hardy, Milne and Freeman carried out upper air trapping by nets hung first from kites and later from tall radio masts (Hardy, Milne and Freeman). Hardy also had nets attached to the masts of ships crossing the North Sea, which were only opened when the ships were more than 50 miles from land. Their results agreed completely with the then unpublished results from the United States, and showed the unexpectedly large numbers of drifting insects that may be present in the upper air. Hardy calculated that on many fine summer days in the area over the North Sea more than 50 miles from land, there were millions of insects drifting above the sea, the majority of which were Aphidae.

There is no doubt that with an easterly wind most of these would arrive alive in Britain.

In 1946 an investigation was started at Rothamsted under the immediate direction of Dr. C. G. Johnson and he was fortunate in being able to establish an excellent co-operation with the Research and Development Establishment of the Ministry of Supply, at their station for Barrage Balloons at Cardington, about 15 miles from Rothamsted. For the first time in this work it became possible to get continuous records, both by day and by night, simultaneously at several definite heights and almost independent of weather conditions.

In the first two years nets were attached to the cables of the balloons at different levels up to 2,000, and occasionally up to 4,000 feet, and the insects were thus filtered out of the air as the wind blew through the nets. Once again all previous results were confirmed with a great increase in reliability of interpretation. On a fine summer day in a net about 3 feet in diameter, at a height of 2,000 feet it was not unusual to get 10 or even 20 living aphids in a single hour. When one considers the microscopic proportion of the air that is being filtered by the net (which is practically invisible at 2,000 feet) it is possible to realize the enormous total population of insects that are being drifted across any mile front of land in any warm summer day.

More recently Johnson has put the work on a still sounder numerical basis by using suction traps which draw a fixed amount of air through the net, almost independent of the wind velocity. This technique enables quantitative results to be obtained even in dead calm weather—as for example may occur at night. A further refinement also enables him to separate the insects caught in each successive hour, so that the times of capture and the relative density for each hour of the day and night can be determined.

The majority of the insects captured in the traps are Aphidae and of these already over 60 species have been identified, of which about 20 species have been found at 1,500 feet or above. In addition to these, species of the following groups have also been observed :—Heteroptera, Homoptera, Diptera, Hymenoptera, Thysanoptera, Neuroptera, Coleoptera, Lepidoptera and Psocoptera.

Johnson's recent results indicate that although the density of insects (i.e., number in a given volume of air) is greater near the ground, the space above is so vast that on an average about 70 per cent of all the insects in the air are above 100 feet from the ground.

Turning away from experimental evidence to field observation we may quote the case recorded by Elton in 1924. He and his colleagues on an expedition to Spitzbergen found living Aphidae on the snow, up to several per square yard in places. The Aphidae were later identified as a species feeding on conifers and the nearest possible food supply was over 800 miles away in the mainland of Europe. At the same time that the Aphidae were found there were also seen a small number of hoverflies (Syrphidae) which are known to be predators on Aphids.

Even in Britain there are many records of the air being full of Aphidae drifting on the wind and also cases when they have been washed up along the tide line of our shores in millions. These swarms are not infrequently accompanied by hover flies and lady-birds, both of which feed on Aphidae.

It is not easy in many of these records to distinguish between migration and drift—and indeed from the purely economic point of view it does not matter so much—but quite recently apparently true migration has been established in the hover flies, by the observations of Lack and others, of Syrphidae passing in very large numbers through passes in the Pyrenees from France to Spain in the autumn in two successive years.

For many years we have had the co-operation of the Masters of many of the Lightships off our coasts, and they have sent in many records and specimens of insects which have come aboard. Between 1933 and 1939 (Gibbs, 1942) ten Lightships, situated from 1 to 30 miles off our south-east and east coasts, sent in about 390 records, and included among these were 120 different species of Lepidoptera, of which about 20 were previously known or suspected to be true migrants As the majority of the species which could be identified belonged to the so-called " Macrolepidoptera "—the figures indicate that at least 10 per cent of our native moths are capable of flying or drifting over the water a minimum of 1 mile and frequently at least 30 miles. Fifty of the 120 species identified were seen on the Outer Dowsing light vessel, which is 30 miles east of Spurn Head in Yorkshire.

Palmèn (1948) records that he examined large numbers of beetles washed ashore in windrows on the coast of Finland. In nine such aggregations over 1,000 species of beetles were represented, some in countless thousands of individuals, and the vast majority were alive. These beetles had probably flown or been carried out to sea by winds, and then brought down to the surface of the sea perhaps by rain, and finally carried back to the shore by surface winds and waves. It is, of course, also possible that they might have been carried out to sea by some flooded river. In either case millions of individuals of hundreds of species have been distributed over quite large distances by wind or water currents and were still alive at the end.

Some years ago I visited the south-western corner of a large lake in Minnesota, U.S.A., just after a strong north-easterly gale. The water line and the shore line was alive with insects, several hundred per square yard, and among these were hundreds of Colorado beetles. These had undoubtedly been blown from the opposite shore which was about 30 miles away. There is little doubt that many of the occasional outbreaks of this insect in Britain are due to adults being blown over from the Continent.

Records and facts of this nature could be quoted almost without end, but enough has been said to show that most of our ideas on the distances that insects can travel—either on their own wings or on the wings of the wind—have altered very considerably in the

last few decades, and may have to be altered still more as our knowledge of the extent of the movements increases.

We have to face the fact that every year millions of millions of insects are distributed by natural causes—migration or drift—over distances to be measured in miles, and not infrequently in hundreds of miles. Among these are some of the major pests of the world—and perhaps to compensate, a small sprinkling of beneficial insects and parasites.

There must follow from this a re-orientation of many old ideas linked up with the prevention and control of outbreaks of insects and of insect-borne diseases.

Firstly, in the case of rotation crops, already mentioned above, it is doubtful if moving a crop from one area to another within any distance less than a few miles, is of any value in the control of the majority of insect pests.

Secondly, the possibility of really exterminating an insect pest becomes untenable, unless it can be done over the whole area of distribution. If an injurious aphid—for example *Aphis fabae*—could be got rid of momentarily in England—say by eliminating its winter food supply—there would be still a constant source of re-infection each summer from the Continent.

Thirdly, the problem of keeping an area free from virus infection takes on new difficulties when we realize that millions of living Aphidae are regularly distributed over distances reaching hundreds of miles; and not to recognize this fact is only to live in a fool's paradise.

Fourthly, some of the activities of quarantine and port inspection of plant imports must be viewed in a new light when we realize that millions of insects per square mile are drifting across the man-made national frontiers, and even over the heads of the inspectors. Inspection is often of great value in preventing the introduction of entirely new pests by artificial means from distant countries, but can do little to reduce the total movement between adjacent areas.

Finally, the knowledge forces us to recognize the international responsibility and the need for co-operation in the control of migrant pests, and of those liable to extensive drift. In the locusts this has already been done to some extent, and with benefit to all: also to a smaller extent with the Colorado beetle situation in western Europe. But more co-operation is needed and Governments must recognize that they have a responsibility to see that insect pests do not leave their country as well as that they do not arrive in it from abroad.

Burgess (A. F.) 1913. *Dispersion of the Gipsy Moth.* (Bull. U.S. Bur. Ent., **119**, 62.)

Collins (C. W.) 1915. *Dispersion of Gipsy Moth larvae by wind.* (Bull. U.S. Dep. Agric., **273**, 1-21.)

Elton (C. S.) 1925. *The dispersal of insects to Spitzbergen.* (Trans. R. ent. Soc. Lond., 289-299.)

Felt (E.P.). 1928. *Dispersal of insects by air currents.* (N.Y. State Mus. Bull., **274**, 59-129.)

FREEMAN (J. A.). 1945. *Studies on the distribution of insects by aerial currents. The insect population of the air from ground level to 300 feet.* (J. Anim. Ecol., **14**, 128-154.)

GLICK (P. A.). 1939. *The distribution of insects, spiders and mites in the air.* (Tech. Bull. U.S. Dep. Agric., **673**, 1-150.)

HARDY (A. C.) and MILNE (P.S.). 1937. *Insect drift over the North Sea.* (Nature, Lond., **139**, 510-511.)

— 1938. *Aerial drift of insects.* (Nature, Lond., **141**, 602-603.)

— 1938. *Studies on the distribution of insects by aerial currents. Experiments in aerial tow-netting from kites.* (J. Anim. Ecol., **7**, 199-229.)

JOHNSON (C. G.). 1950. *The dispersal of insects by wind.* (New Biology no. 9, 76-89.)

1951. *The study of wind-borne insect populations in relation to terrestrial ecology, flight periodicity and the estimation of aerial populations.* (Sci. Prog., no. **154**, 41-62.)

PALMEN (E.). 1948. *Die anemohydrochore Ausbreitung der Insekten als zoogeographischer Faktor.* (Ann. Zool., Soc. Zool. Bot. Fenn. Vanamo **10** (1), 1-262.)

WILLIAMS (C. B.) 1930. *The migration of butterflies.* Edinburgh, Oliver & Boyd.

— 1939. *The migrations of the Cabbage-White butterfly* (Pieris brassicae). (Proc. 7th Inter. Congr. Ent., Berlin, 1, 482-493.)

WILLIAMS (C. B.), COCKBILL (G. F.), GIBBS (M. E.) and DOWNES (J. A.). 1942. *Studies in migration of Lepidoptera.* (Trans. R. ent. Soc. Lond., **92**, 1-283.)

PUBLICATIONS

Physics Department

1. Schofield (R. K.). 1952. *Soil colloids.* (Chemistry and Industry, **4**, 76-78.)

The colloidal particles in soil are for the most part negatively charged, and are therefore surrounded by a Gouy layer within which the cation concentrations increase while the anion concentrations decrease towards the surfaces of the particles. Mr. A. W. Taylor has measured the ratio (activity of HCl) ÷ (activity of $CaCl_2$)$^{\frac{1}{2}}$ and finds it accurately constant for a given soil when the $CaCl_2$ concentration is less than ·01 molar. The ratio (activity of HCl) ÷ (activity of KCl) is constant below ·03 molar KCl and the ratio (activity of HCl) ÷ (activity of NaCl) below ·1 molar NaCl. The departure from constancy must be attributed to the penetration of chloride ions to the inside of the Gouy layer. The critical concentration for sodium is confirmed by the negative anion adsorption of bentonite.

The rate of electrophoretic migration of soil colloids reaches a limit as the electrolyte concentration in the suspending water is progressively reduced. At very low electrolyte concentrations Smoluchowski's equation is inapplicable and the so-called zeta potential calculated with its aid may be several times smaller than the actual difference of electrical potential across the Gouy layer. Using the principles underlying Gouy's theory, both this potential and the number of cations in the Gouy layer can be estimated with fair precision.

These ideas are being applied in a study which Mr. J. P. Quirk of the Australian C.S.I.R.O. Soils Division is making of the fundamental conditions leading to the deflocculation of soil colloids.

2. Penman (H. L.). 1951. *The rôle of vegetation in meteorology, soil mechanics and hydrology.* (Brit. J. appl. Phys., **2**, 145-151.)

Plants transpire large quantities of water at a rate primarily dependent upon weather conditions, and calculable from easily measured weather elements. They therefore play a dominant part in the water and heat balances of the earth's surface, and affect land drainage, underground storage and river flow. Calculation of the transpiration rate can be made the basis of controlled irrigation to produce maximum growth without waste of water, and it is shown that the principle can be applied equally successfully to a field, to a catchment area and to the British Isles as a whole. When the plants grow in a clay soil, shrinkage may occur as the soil dries, with damaging results on roads or buildings carried on the soil.

3. Penman (H. L.). 1951. *The water balance of catchment areas.* (Extrait des procès verbaux des séances de l'Assemblée Générale d'Bruxelles (20-31 Août, 1951) de l'Union Géodésique et Géophysique Internationale.) [In the press.]

Previous work has shown that natural evaporation can be estimated from weather data. For catchment areas the long-period estimate of evaporation obtained in this way should be equal to the difference between measured rainfall and run-off during the same period. A check on 40 British catchments has been successful.

For short periods the balance between rainfall, run-off and evaporation gives a measure of changes in ground storage. Calculations for two British catchments (Stour, 850 km.^{2}; Thames, 9,900 km.^{2}), month by month over periods of 15 and 20 years have shown good agreement with observed movements of well-level, both in long-term trends and in annual cycles. The precision obtainable is greater than that of statistical analysis, and involves the use of fewer arbitrary constants.

Chemistry Department

4. Benzian (Blanche). 1951. *A century-old forest nursery in Germany.* (Forestry, **24**, 36-38.)

A description of techniques.

5. Bremner (J. M.) and Kenten (R. H.). 1951. *Paper chromatography of amines.* (Biochem. J., **49,** 651-655.)

The R_F values on filter-paper chromatograms of a large number of amines in various solvents have been determined.

Ninhydrin was found to be an effective spray for the detection of primary aliphatic amines on paper chromatograms.

The results obtained suggest that amines likely to be present in biological materials could be separated and identified by paper chromatography. Relationships between the molecular structures of the amines studied and their R_F values are discussed.

6. Bremner (J. M.). 1951. *Alkaline decomposition of amino-acids.* (Nature, **168,** 518.)

The effect of hot sodium and barium hydroxides on various amino-acids has been investigated. The results show that, under the conditions generally used for hydrolysis of proteins with alkali, threonine yields glycine and α-amino-n-butyric acid, serine yields glycine and alanine, and cysteine and cystine yield alanine.

7. Chambers (W. E.) and Gardner (H. W.). 1951. *The effect of soil calcium on the mineral content of wheat.* (J. Soil Science, **2,** 246-253.)

Samples of wheat plants were taken on five occasions throughout a season from plots treated 12 years previously with varied dressings of chalk. The pH values of the soil ranged from 4·3 to 6·5 and the yields of wheat from 3·2 to 15·8 cwt. grain per acre. Liming decreased the concentrations and total contents of manganese in the plant and increased the concentrations and total contents of magnesium, but the calcium and potassium concentrations were almost unaffected. Similar results were obtained for other crops in other years. In leys the increased calcium concentration in mixed herbage resulting from liming was due to the higher proportion of legumes and not to changes in the composition of the individual species.

8. Cooke (G. W.). 1951. *Placement of fertilizers for sugar beet.* (J. agric. Sci., **41,** 174-178.)

Ten experiments on sugar beet in 1949 tested a phosphate-potash fertilizer applied in different ways. There was no damage to germination or plant establishment by fertilizer placed in bands 2 in. to the side and 2 in. below the level of the seed.

There were no significant differences between the yields of sugar given by placed and broadcast fertilizer. Similar yields were given by broadcast applications applied early and worked deeply into the seed-bed and by dressings on the seed-bed which were worked in shallowly. Split dressings where half the fertilizer was broadcast and half was drilled beside the seed were not markedly superior to placing or broadcasting all the fertilizer. In most of the experiments placing gave more vigorous growth than broadcasting the fertilizer during late spring and early summer; at harvest this superiority had vanished.

The results of these experiments confirm those carried out in 1947 and 1948. There is no advantage from placing the full dressing of fertilizer beside the seed in districts where the crop is normally grown, except that labour is saved in applying the fertilizer.

9. Cooke (G. W.). 1951. *Fixation of phosphate during the acid extraction of soils.* (J. Soil Sci., **2,** 254-262.)

Preparations of the hydrous oxides of titanium, aluminium, and iron suspended in 0·5 N acetic acid fixed considerable amounts of added phosphate. Tests were made to prevent fixation at pH 2·5 by dissolving reagents in the acetic acid. 8-hydroxyquinoline reduced fixation by each of the three oxides, and selenious acid prevented fixation completely. Citric acid prevented fixation by ferric oxide. Citrate, oxalate, fluoride, ferrocyanide, morin, and quinalizarin all reduced fixation by alumina. Selenious acid prevented most of the phosphate fixation caused by a laterite soil at pH 2·5.

Kaolinite and halloysite fixed very small proportions of added phosphate.

at pH 2·5 and at pH 4·5. Bentonite fixed appreciable amounts of phosphate at pH 2·5. Selenious acid did not reduce fixation by any of these clay minerals.

Small amounts of the phosphate added as dicalcium phosphate and mineral phosphate were recovered when laterite soils were extracted with 0·5 N acetic acid. Satisfactory amounts of the added phosphate were recovered when selenious acid was present in the extractant.

In a series of British soils from manuring experiments on sugar beet there was very little fixation of added phosphate during extraction at pH 2·5; there was no advantage from adding selenious acid to prevent fixation. Six other selected British soils fixed considerable amounts of added phosphate at pH 2·5. Selenious acid prevented varying proportions of the fixation caused by five of the soils and had no effect on fixation by the sixth soil.

10. Cooke (G. W.). 1951. *The mechanical application of fertilizers in field experiments.* (Empire J. exp. Agric., **19**, 160-174.)

In field experiments fertilizers must be applied with greater precision than is necessary in general farm practice. Three mechanisms commonly fitted to commercial fertilizer distributors were tested in models to determine their suitability for applying experimental dressings. Tests were also made on a top-delivery drill built specially for experimental work.

Machines incorporating revolving plates or star-wheels delivered granular and powdered fertilizers uniformly in laboratory tests. A thick star-wheel delivering fertilizer mainly from the spaces between the teeth gave more constant rates than a thin wheel which delivered fertilizer both between the teeth and on the surface of the wheel. A vertical-wheel model machine delivered fertilizers very unevenly and drills incorporating such a mechanism would not be satisfactory for use in field experiments.

Granular fertilizer was generally delivered more uniformly from all machines than a powder of the same composition. Powdered fertilizer absorbed much more water from the air than granular material. All the mechanisms tested delivered dry powder more regularly than damp powder.

Irregular delivery of well-conditioned fertilizer is due to several causes. Alterations in bulk density of the material affect all conventional distributors. Where the surface of a wheel or plate is used to dispense fertilizer from the hopper, "slip" between the wheel surface and the fertilizer may be caused by high speeds or by using damp fertilizer. Gravity-feed from a hopper to a toothed wheel is likely to be unsatisfactory unless free-flowing fertilizers are used and an efficient agitator is fitted. Efficient agitation may be secured by arranging horizontal wheels so that they occupy a large part of the hopper bottom. Gravity-fed mechanisms may not deliver constant amounts of fertilizer after three-quarters of the total capacity of the hopper has been delivered. Distributors incorporating wheels having widely spaced teeth deliver different amounts of fertilizer to consecutive lengths of row since delivery is governed by the position of the teeth of the wheel in relation to the hole that allows fertilizer to fall down the delivery tube.

11. Cooke (G. W.). 1951. *Fertilizer placement machinery.* (J. Inst. Brit. agric. Engineers, **8**, 1; 7-14.)

The value of special methods of applying fertilizers for common arable crops is stated, and experiments made to determine the most satisfactory positions for placing bands of fertilizer are described. Machines built to place fertilizer in a zone near to the seed must be fitted with suitable fertilizer delivery mechanisms and coulters. The characteristics of fertilizer placement machines used on British farms are discussed.

12. Cooke (G. W.). 1951. *How to apply fertilizers for sugar beet.* (Brit. Sugar Beet Rev., **20**, 65-70.)

A review of recent experimental work comparing different methods of applying fertilizers for sugar beet.

13. Crowther (E. M.). 1951. *Experimental agriculture.* (Advanc. Sci., **8**, 236-248. Reprinted in Brit. agric. Bull., **4**, 200-206; summary in Nature, **168**, 232.)

Presidential address to the Agriculture Section of the British Association at the Edinburgh Meeting.

14. Crowther (E. M.). 1950. *Committee on nutrition problems in forest nurseries. Summary report on* 1948 *experiments.* (For. Comm. Rept. on For. Res., 1948-9, 60-64.)

15. Crowther (E. M.). 1951. *Committee on nutrition problems in forest nurseries. Summary Report on* 1949 *experiments.* (For. Comm. Rept. on For. Res., 1949-50, 97-105.)

Annual reports on investigations reviewed in the Rothamsted Report for 1949, 122-129.

16. Crowther (E. M.), Warren (R. G.), Nagelschmidt (G.) and Cooke (E. H.). 1951. *The production and agricultural value of silicophosphate fertilizers. Part V. Laboratory and Pot Culture Investigations.* (Min. Supply Perm. Records Res. and Dev., No. 11, **108,** 146-209.)

This paper and the following one summarize the agricultural side of a joint investigation by the Building Research Station and the Rothamsted Chemistry Department initiated in 1940 and continued for many years.

The Building Research Station prepared a range of high temperature phosphates or " silicophosphates " by heating phosphate rock with soda-ash and sand, giving special attention at first to materials like Rhenania phosphate with about four parts phosphate rock to one part soda-ash, and, later, to " low-soda silicophosphates " with about six parts phosphate rock to one part soda-ash.

A large number of the early burns on the 10g. scale were analysed at Rothamsted by methods adopted for speed and convenience in developmental work on production. Representative samples were compared with equal amounts of phosphorus in superphosphate and Bessemer basic slag in small scale pot experiments on radishes, using soils covering a range of pH values. The results showed that the 2 per cent citric acid method used in the United Kingdom for analysing basic slags was suitable for silicophosphates. The pot experiments showed that for a given content of citric-soluble phosphorus there were no appreciable yield differences between silicophosphate prepared with high or low proportions of soda-ash, from different kinds of phosphate rock or with varying proportions of fluorine remaining from that in the original rock. The relative values of silicophosphates, basic slags and superphosphate were similar on many kinds of soil and for many other crops. There were indications that the basic materials, silicophosphates and basic slags, were slightly more effective than superphosphate on very acid soils and somewhat less effective on neutral ones. It was confirmed for basic slags of current production that the manurial value and citric solubilities fall off regularly as the fluorine contents rise. The later large-scale productions of silicophosphate had low fluorine contents but some of the early experimental batches had relatively high fluorine contents. This did not reduce the availability of the phosphorus to plants. Whereas fluorine forms a very insoluble fluorapatite in low-soluble open-hearth basic slags, it appears to remain as a simple fluoride in silicophosphates.

17. Crowther (E. M.) and Cooke (G. W.). 1951. *The production and agricultural value of silicophosphate fertilizers. Part VI. Field Experiments.* (Min. Supply Perm. Record Res. and Dev., No. 11, **108,** 210-283.)

Results are presented for 130 field experiments carried out from 1941 to 1946 to assess the agricultural value of silicophosphates. In 18 experiments on swedes in 1942 high-soda and low-soda silicophosphates gave almost identical results, somewhat higher than from equivalent amounts of superphosphate. In 11 of these experiments silicocarnotite gave lower yields than the two soda-silicophosphates. In 29 experiments on swedes in 1943-6 low-soda silicophosphate was slightly inferior to superphosphate. In general, for swedes on very acid soils, silicophosphate was equivalent to superphosphate and on less acid and neutral soils inferior to superphosphate. In 38 experiments on potatoes silicophosphate gave yields similar to those from superphosphate on very acid soils, but on less acid and neutral soils silicophosphate was only two-thirds as efficient as superphosphate. In small

numbers of experiments on other crops silicophosphate was slightly better than superphosphate on sugar beet but not on oats. In experiments on permanent grass and on the establishment and growth of reseeded grass silicophosphate gave results very similar to those from Bessemer basic slag and slightly better than those from superphosphate.

18. Heintze (S. G.) and Mann (P. J. G.). 1951. *A study of various fractions of the manganese of neutral and alkaline organic soils.* (J. Soil Sci., **2**, 234-242.)

In a series of neutral and alkaline soils with a wide range of organic matter content the percentage of the total soil manganese extracted by neutral ammonium acetate containing 0·2 per cent hydroquinone decreased with increase in soil organic matter.

Evidence was obtained that the low values for hydroquinone-soluble manganese with the soils of high organic-matter content were due, at least in part, to retention by the soil organic matter of the divalent manganese formed by reduction.

Under the conditions used the manganese minerals hausmannite and manganite were more readily reduced by sodium hydrosulphite than by hydroquinone.

The manganese extracted from organic soils by neutral ammonium acetate containing 0·4 per cent hydrosulphite was generally greater than that if 0·2 per cent hydroquinone was used. The interpretation of these differences is complicated by the effect of hydrosulphite on the retention of divalent manganese by the soil organic matter.

Pedology Department

19. Stephen (I.) and MacEwan (D. M. C.). 1951. *Some chloritic clay minerals of unusual type.* (Clay Minerals Bull., **1**, 5, 151-162.)

In addition to the swelling chlorite previously reported (Ann. Rep. 1949) a description is given of a mineral separated from the weathering crust of an appinite, which shows a regular interleaving of swelling chlorite layers with non-swelling chlorite.

20. Muir (A.). 1951. *Notes on the soils of Syria.* (J. Soil Sci., **2**, 163-182.)

An account is given of the main soil groups occurring in Syria together with chemical and clay mineral data. The main soil groups recognized are, in the desert, brown desert soils and solonchakous soils, with undeveloped soils corresponding in some features to the Russian sierozem and possibly to reddish chestnut soils; in the Mediterranean zone *terra rossa* and brown soils on basalt, with gley soils on alluvial flats. The effect of parent material is well marked in all the zones. The occurrence of attapulgite in some of the desert and steppe soils is reported. Under comparable conditions well crystallized basalt gives rise to a kaolin mineral on weathering, whereas a glassy rock yields a montmorillonoid.

20a. Bloomfield (C.). 1951. *Experiments on the mechanism of gley formation.* (J. Soil Sci., **2**, 196-211.)

Soil Microbiology Department

21. Skinner (F. A.), Jones (P. C. T.) and Mollison (J. E.). 1952. *A comparison of a direct and plate counting technique for the quantitative estimation of soil micro-organisms.* (J. gen. Microbiol.) [In the press.]

Estimates of numbers of micro-organisms occurring in three differently manured soils, made by a direct counting and plating technique were compared. No correlation was found between the two methods and reasons for the large discrepancy between them are discussed. Contradictory information of the effect of external factors on soil micro-organisms can be given by the two different methods of counting.

22. Nutman (P. S.). 1951. *Studies on the physiology of nodule formation. III. Experiments on the excision of root-tips and nodules.* (Ann. Bot., N.S., **16**, 79-101.)

The excision of nodules and root-tips from red clover inoculated with an effective strain of nodule bacteria leads to an increase in the number of nodules subsequently formed. This is thought to be due to the removal by excision of the source of an inhibitor. In the nodule the inhibitory activity appears to be centred in the growing point and not in the bacterial tissue since the excision of the nodular meristem only will stimulate further nodulation. The response to excision depends upon the number of excisions made and is inversely related to the inherent susceptibility of the individual plant.

Excision of nodules from plants inoculated with ineffective strains of bacteria has no influence on further nodulation, presumably because the growing points of the nodules are abortive.

23. Nutman (P. S.) and Read (Margaret P.). *Symbiotic adaptation in local strains of red clover and nodule bacteria.* (Plant and Soil **4**, 57-75)

A study has been made of the response of local strains of British and Swedish red clover in symbiosis with nodule bacteria isolated from the localities from which the plant strains were obtained. All combinations of bacterial isolate and plant type were examined under bacteriologically controlled conditions of plant culture on an agar medium.

In the Swedish material each local strain of clover responded most effectively with bacteria isolated from its own locality. This adaptation was detected at about eight weeks from planting by scoring the seedlings for size and colour, and at harvest was reflected in a mean difference of 5 per cent on a dry weight basis. No differences were found in nitrogen content.

No adaptation was found with the British material possibly because of the more uniform climatic conditions. A small intranational adaptation was significant.

24. Nutman (P. S.). 1951. *Colour reactions between clay minerals and root secretions.* (Nature, **167**, 288.)

Wyoming bentonite, and to a lesser extent, fuller's earth, were observed to give a marked blue-green colour in the neighbourhood of red clover roots when incorporated into a medium in which the plants are grown. *Vicia hirsuta* under similar conditions gives an orange colour with bentonite, flax yellow and oats and a number of other species no colour. The coloured mineral taken from the neighbourhood of clover roots is sensitive to pH ; at high pH it is decolourized, but on reacidifying the colour is restored. The colour is insensitive to oxidizing or reducing agents and is not readily removed by solvents. Failure to elute a coloured substance from the bentonite suggest that a chemical reaction is involved between the clay and substance secreted by the root.

25. Kleczkowska (Janina). 1950. *A study of phage-resistant mutants of Rhizobium trifolii.* (J. gen. Microbiol., **4**, 298-310.)

Phage-resistant mutants were obtained from four strains of *Rhizobium trifolii.* Mutation to phage resistance tended to coincide with mutations in other features, such as morphology of colonies or effectiveness in nitrogen fixation. The accompanying mutations occurred independently, and their frequency varied widely from strain to strain.

Some mutants seemed stable in their newly acquired features ; others continued to mutate at high rates.

Some of the mutants as regards nitrogen fixation were stable or could eventually be stabilized but other mutants derived from one of the parent strains remained unstable even after several successive replatings or passages through nodules.

26. Kleczkowski (A.) and Kleczkowski (Janina). 1951. *The ability of single phage particles to form plaques and to multiply in liquid cultures.* (J. gen. Microbiol., **5**, 346-356.)

The results of testing a bacteriophage to a strain of clover nodule bacteria using young (1 day) and old (5 days) bacterial cultures both fit to the hypo-

thesis that phage multiplication can be initiated by single phage particles. As the same phage preparations gave more plaques on solid media and higher proportions of liquid cultures in which phage multiplication could be detected, with young than with old bacterial cultures, the fit to the hypothesis is not evidence that every single phage particle will multiply. It may be so when young bacterial cultures are used, although there is no positive evidence for it. With older bacterial cultures definitely only a proportion of viable phage particles succeed in starting phage multiplication, the proportion decreasing with the increasing age of bacterial cultures used for testing.

Botany Department

27. Humphries (E. C.). 1951. *The absorption of ions by excised root systems. II. Observations on roots of barley grown in solutions deficient in phosphorus, nitrogen or potassium.* (J. exp. Bot., **2**, 344-379.)

Barley plants were grown in complete culture solution and in deficiencies of phosphorus, nitrogen or potassium for a period of about six weeks. Excised roots of these plants were treated with a complete, aerated culture solution at 25°C for varying periods of time, and the changes in respiration rate, phosphorus, nitrogen, potassium, sugars and starch contents measured.

The dry weight decreased with time but the water content changes varied with treatment.

In all cases the deficient roots increased in content of the element in which they were originally deficient. The roots of the plants supplied with full nutrient usually decreased in content of phosphorus, nitrogen and potassium, but exceptions occurred and the reasons are discussed. In most of the experiments described simultaneous loss of one ion and gain of another occurred. Nitrogen-deficient roots accumulated nitrate when exposed to a complete nutrient solution, and some of this was assimilated with formation of protein. Under similar conditions nitrogen-rich roots decreased in nitrogen content and proteolysis took place.

There was a rapid fall in sucrose and reducing sugar content of the excised roots. The starch content was initially very small and showed little change with time.

The respiration rate declined with time in all treatments except where a nitrogen deficiency existed. Here the respiration rate increased to a maximum value at about eight hours and then fell. This increase in rate is attributed to protein synthesis. No evidence of a " salt respiration " was observed even when active uptake of phosphorus or potassium was occurring. In most instances the carbon dioxide evolved in respiration greatly exceeded the carbon dioxide equivalent of the sugar consumed in the same period. Exceptions were found with the nitrogen-deficient roots where less carbon dioxide was evolved than the equivalent of sugar consumed. It is probable that a part, at least, of the sugar unaccounted for was used in protein synthesis. Where the carbon dioxide of respiration was in excess of the equivalent of sugar consumed, protein or amino-acid is the most probable substrate. Respiration rate was found to be related both to nitrogen and sugar content.

Statistical examination of the data revealed that the gain or loss of an element showed a quadratic relationship with time. The rates of gain or loss of each element in each experiment was calculated at 0 hr. and 16 hr. There was a negative correlation between rate and content of element and a positive correlation between rate and sugar content. Thus for a given sugar content there was a critical concentration of element above which loss occurred and below which gain occurred. Similarly for a given content of element there was a critical sugar content below which loss, and above which gain, of element occurred. The effect of one element on uptake of another was investigated and it was concluded that in most cases the uptake of any element was virtually independent of others.

The changes in water content of the excised roots was found to be related to the rate of potassium uptake in some instances.

The conclusions to be drawn from these experiments are discussed in the light of current theories. The present results do not support the theory of " salt respiration " nor the alternative theory which postulates that active

protein synthesis is a prerequisite of salt uptake. It was found that active uptake could occur simultaneously with marked proteolysis. The uptake observed could not be explained on the basis of ion exchange.

28. HUMPHRIES (E. C.). 1952. *The absorption of ions by excised root systems. III. Observations on roots of pea plants grown in solutions deficient in phosphorus, nitrogen or potassium.* (J. exp. Bot., **3**.) [In the press.]

Pea plants were grown in complete culture solution and in deficiencies of phosphorus, nitrogen or potassium for a period of about five weeks. Excised roots of these plants were treated with a complete, aerated culture solution for varying periods of time and the changes in respiration rate, phosphorus, nitrogen, potassium, sugar and starch contents measured.

There were changes in fresh weight and dry weight of the excised roots during treatment. The dry weight decreased with time but the water content changes were variable. Uptake of water was correlated with uptake of potassium and sucrose content in some instances.

There was no evidence of a " salt respiration " in those cases where active accumulation occurred.

The rates of gain or loss of phosphorus, nitrogen or potassium at 0 hr., 8 hrs. and 16 hrs., were calculated and it was found that the rate depended both on content of element in the root and the sugar content. There was very little evidence that one element affected the rate of uptake of another. Simultaneous loss of one element and gain of another occurred in some instances.

The observations appear to be best explained on the assumption that the absorbed ions are fixed in the cells in the form of loosely bound compounds and that these compounds are formed from sugars.

29. OWEN (P. C.). 1952. *The relation of germination of wheat to water potential.* (J. exp. Bot., **3**.) [In the press.]

The relation of water potential to the germination of wheat was studied by supplying water to the seeds in the vapour phase, at controlled relative humidities. An apparatus for this purpose and a method of attaining the necessary precise control of temperature are described.

The critical level of water potential at which germination is completely inhibited was not reached. Even when, as a result of infection, the duration of the experiments was limited to 20 days, up to 20 per cent of the seeds germinated at a potential of —320 metres of water or a pF of 4·5. This is considerably drier than Permanent Wilting Point, which is represented by a potential of —160 metres of water, or pF 4·2. There was a marked effect of water potential on the time taken to germinate ; this varied from 2 to over 20 days with variation of water potential of from zero to —320 metres. It is probable that very little further germination would have occurred after 15 days had not fungal infection enabled the seeds to obtain liquid water by bridging the air gap between seed and water source. This infection was probably responsible for the reduction in viability of the seeds at the lower potentials ; the delay of germination that occurred in these conditions appeared to increase the susceptibility of the seeds to infection.

The failure of some individual seeds to germinate at potentials which allowed other seeds to germinate was not due to failure to attain a critical moisture content.

In soil, the percentage germination at low potentials was similar to that observed without soil, but the reduction in the total germinating capacity, or viability, after 20 days was not as great, and this was probably due to the reduced incidence of visible infection observed under these conditions.

30. OWEN (P. C.). 1952. *The relation of water absorption by wheat seeds to water potential.* (J. exp. Bot., **3**) [In the press.]

The relation of water absorption by wheat grains to water potential was studied by supplying water to the seeds in the vapour phase at controlled potentials.

At a potential of —250 metres of water, the curve of water uptake against time demonstrates exponential approach to equilibrium moisture content, and living and dead seeds behave similarly until germination effects are

apparent in the former. It is probable that water uptake in these early stages is due to physical, rather than physiological processes. Germination, when it occurs, causes an exponential rate of increase in the seed weight.

At higher potentials, up to zero, the uptake curves for dead seeds depart from the simple exponential relationship, and it is postulated that the total curve is made up of such an exponential curve plus a curve showing increase of rate with time to a constant rate. It is suggested that the first curve represents the physical process of imbibition by the starch, while the second represents the initiation and progress of starch hydrolysis.

A parameter *a*, used in the formula derived for the curves, is interpreted as representing the diffusivity of water vapour in the seed material, depending upon the physical properties and dimensions of the seed.

31. Thurston (Joan M.). 1951. *Some experiments and field observations on the germination of wild oat* (Avena fatua *and* A. ludoviciana) *seeds in soil and the emergence of seedlings.* (Ann. appl. Biol., **38**, 812-832.)

The distinguishing characters of *Avena fatua* and *A. ludoviciana* are described.

Pot experiments and field observations showed that most seeds of *A. fatua* germinated in spring and a few in autumn ; hardly any germinated in summer or winter. Seeds of *A. ludoviciana* germinated in winter only. The greatest depth of sowing from which seedlings of either species reached the surface was 9 in., but seedlings from this depth were weak and yellow when they first appeared. *A. ludoviciana* gave more and sturdier seedlings than *A. fatua* from 6 in. and 9 in. depths. There was no evidence of induced dormancy in seeds of *A. fatua* buried at depths down to 20 in. Germination of this species was hastened by monthly cultivation of the soil. The maximum survival of *A. fatua* was three years in pots and slightly longer in the field ; seeds of *A. ludoviciana* in pots survived only two years. The two or three seeds of each spikelet of *A. ludoviciana* germinated in turn, starting with the largest, but the interval between germination of successive seeds varied.

Seedlings from freshly-sown seeds of both species were more vigorous than seedlings from seeds which had been buried for a year or more. Germination and subsequent growth of both species took place in soil of pH 4·5 to 7·0 approx.

32. Warington (Katherine). 1951. *Some interrelationships between manganese, molybdenum and vanadium in the nutrition of soybean, flax and oats.* (Ann. appl. Biol., **38**, 624-641.)

Soybean and flax were grown in nutrient solutions containing high and low levels of molybdenum and vanadium, in combination with toxic (10-25 p.p.m.) and non-toxic (1 p.p.m.) manganese. Molybdenum (20 and to a less extent 10 p.p.m.) intensified the chlorosis induced by manganese excess, though these concentrations were harmless in the presence of 1 p.p.m. Mn. Vanadium (≡1·0, 5 and 10 p.p.m. Mo) counteracted some of the symptoms of manganese toxicity, but the two higher rates were harmful to growth irrespective of the manganese supply. Toxic concentrations of vanadium at first deepened the green colour of the shoot, though apical iron-deficiency chlorosis was generally induced later. Low molybdenum (0·1 p.p.m.) or equivalent vanadium had no influence on growth or iron nutrition at either level of manganese. Visual differences were corroborated by changes in the nitrogen, phosphorus and iron contents of the plants. There was no evidence of replaceability of molybdenum by vanadium.

Oats were grown in nutrient solutions containing various combinations of manganese (nil-400 p.p.m.) and molybdenum (nil-20 p.p.m.). The appearance of manganese-deficiency symptoms was not affected by the quantity of molybdenum provided, and the manganese and molybdenum contents of the leaves were mutually independent of the quantity of each element supplied.

Statistics Department

33. Boyd (D. A.). 1951. *Economic and statistical aspects of animal and vegetable foods.* (Brit. J. Nutrition, **5**, 255-260.)

This paper formed one of a series given to a conference of the Nutrition Society on the comparative merits of animal and vegetable foods in nutrition.

The relative physiological efficiencies of the different farm animals is discussed and the paper goes on to consider how far these purely physiological measures of efficiency need to be qualified by economic considerations.

34. Boyd (D. A.). 1952. *The effect of seed rate on yield of cereals.* (Emp. J. exp. Agric.) [In the press.]

The results of all available experiments carried out in the British Isles on the effect of seed rate on the yield of cereals have been summarized, together with some data for Scandinavian countries. A substantial number of experiments were traced for winter wheat and for spring barley and oats; most of the experiments on spring oats were from the north and west of the country. The main conclusion to be drawn from the data is that the optimum seed rates (about 2 bu./acre for wheat and barley and 4-5 bu./acre for oats) are considerably below those commonly in use.

Information on the influence of other factors such as time of sowing, row spacing and nitrogen dressings was scanty. Six experiments with both seed rate and nitrogen dressings as factors suggested that nitrogen responses increased slightly as seed rate increased, but the greater response was sufficient only to balance the cost of the extra seed. The results of the Scandinavian experiments showed a definite but small increase in the percentage of lodging with higher seed rates. There was some indication that, for each cereal, lower seed rates were most successful in conditions of high fertility as judged by the level of mean yield.

There seems little need for further experiments testing seed-rates alone, except perhaps on spring wheat, but simple factorial experiments including comparisons between varieties, nitrogen dressings and perhaps sowing dates in addition to seed-rates would indicate how far the foregoing conclusions need to be modified with respect to these factors as well as for different soil types.

35. Dyke (G. V.) and Patterson (H. D.). 1952. *Analysis of factorial arrangements when the data are proportions.* (Biometrics.) [In the press.]

Methods of analysis of results from factorial arrangements are well known when the data are, for example, yields. In this paper a method, applicable whether the numbers of observations are equal or, as is more usual in survey work, unequal, is given for the case in which the data are proportions. The data are subjected to a transformation (here the logit transformation is suggested) such that in the new scale of measurement observations can reasonably be represented as linear functions of a number of parameters. Maximum likelihood estimates of these parameters are then found.

36. Dyke (G. V.) and Simpson (Emily P.). 1952. *A collaborative investigation into three methods of chemical analysis of ground Pyrethrum flowers.* (Appl. Statistics.) [In the press.]

The application of analysis of variance to an international collaborative investigation is described. Two bales of pyrethrum flowers were ground and samples of each were sent to 42 analysts in 14 countries. Duplicate determinations of pyrethrin content were made on each sample by each analyst.

The variation in the determinations by each of the analytical methods used is shown to consist of four main components; one arising from consistent differences between analysts, the second from the large difference in pyrethrin content between the bales, the third from the variation between analysts' estimates of the difference between bales, and the fourth (relatively small) from differences between the determinations made by each analyst. Increasing the number of replicate determinations made by one analyst will not provide results appreciably more consistent with those of other analysts.

The analysts were classified into two groups for each method according to their previous experience. Apparently while experienced analysts can reproduce their results with greater precision than those with little experience in the methods, the variation between analysts is greater in the case of the experienced analysts.

37. Ellison (W.) and Boyd (D. A.). 1952. *The possibilities of marginal land reclamation : some results of a survey in England and Wales.* (J. R. agric. Soc.) [In the press.]

The results are described of a survey of marginal land in England and Wales undertaken at the request of the Agricultural Research Council in the latter part of 1949. The survey was carried out in Wales and in northern and south-western England by three independent teams of fieldmen drawn largely from members of the N.A.A.S. in the provinces concerned.

The total acreage of marginal land in private occupation is estimated at about 2·4 m. acres of which 1·0 m. acres is in Wales and the Welsh Border counties and the rest about equally divided between the northern and south-western counties of England. It is tentatively estimated that there is in addition a further 0·5 m. acres of common grazings in marginal land areas.

Visits to almost 200 farms in East Wales and northern England provided considerable information on what improvements to the land and the farmsteads are likely to be practicable, on the probable cost of these improvements and on the increased returns which they could be expected to provide.

The total capital investment required was estimated at £40-45 per acre improved, rather less than half being for improvements to the land in the form of additional cultivations, manuring, drainage and fencing, and most of the remainder for the construction of additional buildings, roads and services or for their repair or replacement.

As a result of this expenditure it is estimated that, leaving aside the acreage regarded as not worth improving, the present output per acre of marginal land could be increased by about 70 per cent above its present value. The additional annual output per 100 acres would be equivalent to about 10 two-year old store cattle or 2·3 tons of meat.

38. Grundy (P. M.). 1951. *The expected frequencies in a sample of an animal population in which the abundances of species are log-normally distributed. Part I.* (Biometrika, **38**, 427-434.)

In the statistical analysis of animal populations, it is of interest to study the frequency distribution of species represented in a sample by 1, 2, 3 . . . individuals. The logarithmic series has been fitted to such data with considerable success since it was put forward by R. A. Fisher, A. S. Corbet and C. B. Williams in the Journal of Animal Ecology, 1943 ; but some discrepancies have subsequently appeared in data from very large samples. The present paper discusses one of the alternative distributions which have been suggested, based on the assumption of a log-normal distribution of abundances in the population. Part I gives tables of the expected number of species in the sample and the expected number of singletons as fractions of the number of species in the population. Punched-card apparatus was used to calculate the tables. A further paper is being prepared, giving methods of calculating the rest of the distribution and of fitting it to observational data.

It has been pointed out by Dr. D. J. Finney that the function " ϕ_0 " of the present paper also gives the probability of a sterile plate in the plate-count method of estimating bacterial density, when the logarithm of the inoculum-size is normally distributed.

39. Healy (M. J. R.). 1952. *Latin rectangle designs for 2^n factorial experiments on* 32 *plots.* (J. agric. Sci.) [In the press.]

Designs are described for factorial experiments with 3, 4 or 5 factors at 2 levels each, using 32 plots in a 4 by 8 layout on the ground. The effects of both rows and columns can be eliminated from the estimate of error. Provided that three-factor interactions can be ignored, information can be retained on all two-factor interactions.

40. Healy (M. J. R.). 1952. *A table of Abbot's correction.* (Ann. appl. Biol., **39**) [In the press.]

In tests of insecticides, etc., if a response of P_0% occurs in nutreated material, an observed response of P'% can be corrected to give the true response to the treatment P'% by the formula

$$P' = \frac{P\text{-}P_0}{100\text{-}P_0} \frac{100\text{-}P'}{}$$

A table is given of the correction term for values of P_0 from 1-25%.

41. Patterson (H. D.). 1952. *The construction of balanced designs for experiments involving sequences of treatments.* (Biometrika., **39**) [In the press.]

The mathematical theory of the construction of experimental arrangements such as those which are used in change-over trials is developed. The properties of the designs and in particular requirements of balance are discussed in detail. Methods of construction are then given for designs with 3, 4, 5 and 6 periods and requiring 60 or fewer units. A number of designs outside this range are also included. There are still a number of designs which have neither been found nor proved non-existent, particularly for non-prime numbers of treatments.

42. Yates (F.). 1951. *The analysis of a rotation experiment.* (Bragantia.) [In the press.]

The paper describes the statistical analysis of a rotation experiment in which continuous maize and continuous cotton are contrasted with rotations involving cotton, maize and leguminous crops. Not all phases of each rotation were included in the experiment and the analysis is consequently considerably more complicated than would be the case in a well-planned experiment. The method followed is to fit constants by least squares, including a constant for the deterioration of the continuous cropping. The contributions of the various sources of variation to the experimental errors are also analysed.

43. Yates (F.). 1952. *Trials of coffee progenies.* (Biometrics.) [In the press.]

The arrangement of progeny trials of such plants as coffee in which vegetative reproduction is not practicable is discussed. The general problem is to select the best progenies and the best individual plants within progenies. Estimates are also required of the genetic variance within progenies for the various groups of progenies, and also of the genetic variance between progenies. This is made possible by the existence of plants from duplicated haploid homozygous lines which are similar in habit or growth and yield characteristics to the lines to be tested.

44. Yates (F.). 1951. *Sampling methods in surveys.* (Proc. Inst. Brasileiro de Geogr. e Estatistica.) [In the press.]

This is an expository paper given to the Instituto Brasileiro de Geografia e Estatistica.

45. Yates (F.). 1952. *Crop prediction in England.* (Proc. int. Stat. Inst.) [In the press.]

The paper gives an account of the work that has been done in recent years in England on the estimating and forecasting of the yields of agricultural crops. The subjects mainly dealt with are the estimation and forecasting of the mean yield per acre. The findings of the Survey of Maincrop Potatoes are described as well as the results of the Agricultural Meteorological Scheme involving sampling observations on the growing wheat crop. The general principles to be followed in estimation and forecasting of the yield per acre are outlined.

46. Yates (F.) and Boyd (D. A.). 1951. *The survey of fertilizer practice: an example of operational research in agriculture.* (Brit. agric. Bull., **4**, 206-209.)

This paper was read at the Edinburgh meeting of the British Association and describes how during the war the need for greatly increased food production demanded that the maximum use be made of fertilizers. On the other hand, the shortages of shipping, etc., made it imperative that such supplies as were available were employed to the best advantage. This required not only a better knowledge of the responses of the various crops, but also a knowledge of the way in which farmers actually used their fertilizers. To this end a Survey of Fertilizer Practice (which is still being continued)

was instituted. The paper describes the methods and results of this survey and of the other steps that were taken to ensure a rational fertilizer policy. The whole investigation provides a good example of what is now known as operational research, and illustrates the uses and limitations of the survey technique in agriculture, and its relation to planned experimentation.

CORRESPONDENCE AND REVIEWS

47. Yates (F.) and Healy (M. J. R.). 1951. *Statistical methods in anthropology.* (Nature, **168,** 1116.)

48. Yates (F.). 1951. *Review : " Contributions to Mathematical Statistics " by R. A. Fisher.* (Nature, **168,** 308-309.)

49. Yates (F.). 1951. *Review : " Experimental Designs " by William G. Cochran and Gertrude M. Cox.* (Sci. Progr., **39,** 353-354.)

REPORTS

50. Avis (P. R. D.) and Price (C. D.). 1951. *Survey of maincrop potatoes : Northern Province.*

51. Boyd (D. A.) and Dyke (G. V.). 1951. *The place of statistics in field experiments.*

52. Boyd (D. A.) and others. 1951. *Factors influencing the yield of winter beans.*

53. Church (B. M.), Blenkinsop (A.) and others. 1951. *The Survey of Fertilizer Practice,* 1950.

54. [Davies (A. J.)] and Lord (Rowena). 1951. *Survey of Brassica crops in Wales.*

55. [Edwards (D. E.)] and Boyd (D. A.). 1951. *Results of a survey of ragwort infestation in two areas in Wales.*

56. Healy (M. J. R.). 1951. *Statistical techniques in biology.*

57. Lessells (W. J.). 1951. *Investigation into the varieties of cereals grown in England and Wales,* 1947-50.

58. Lessells (W. J.). 1951. *A collaborative study of the analytical methods used in feeding stuffs analysis : Preliminary statistical report.*

59. Simpson (Emily P.) and Boyd (D. A.). 1951. *Report on a soil sampling investigation.*

60. [Williams (R.)], Church (B. M.) and Lord (Rowena). 1951. *Survey of Fertilizer Practice, Cardiganshire. Report on the* 1945 *and* 1950 *surveys.*

61. Yates (F.). 1951. *The use of road traffic counts to estimate the volume of road goods traffic.* (Note prepared at the request of the Working Party of Experts on Statistical Information, Inland Transport Committee, E.C.E.)

62. Yates (F.). 1951. *Methods of " selecting " vehicles to be sampled.* (Note prepared at the request of the Working Party of Experts on Statistical Information, Inland Transport Committee, E.C.E.)

Plant Pathology Department

BOOK

63. Bawden (F. C.). 1950. *Plant Diseases.* (Revised Edition.) Edinburgh, Nelson.

GENERAL PAPERS

64. Bawden (F. C.). 1951. *Growing healthier crops.* (*In:* Four Thousand Million Mouths, edited by F. Le Gros Clark and N. W. Pirie. Oxford Univ. Press.)

65. Bawden (F. C.). 1951. *The control of virus diseases.* (Proc. Int. Conf. Crop Protection.)

66. Bawden (F. C.). 1951. *Viruses, organisms or molecules,* (Discovery, Feb. 1951.)

67. Bawden (F. C.). 1952. *The interaction between virus and host cell.* (Proc. 2nd. Int. Poliomyelitis Conf.)

68. Bawden (F. C.) and Pirie (N. W.). 1952. *Physiology of plant virus diseases.* (Ann. Rev. Plant Physiol.)

69. Broadbent (L.). 1950. *In search of better potatoes.* (The Farmer (Natal), **39,** 7.)

70. Broadbent (L.). 1951. *Lettuce mosaic in the field.* (Agriculture, **57,** 578-582.)

71. Broadbent (L.). 1951. *Birds and rodents in relation to agriculture.* (Nature, Lond., **167,** 717-719.)

72. Hull (R.). 1951. *Report on Virus Yellows in Europe.* (Int. Inst. Sugar Beet Res., XIV Congress.)

73. Hull (R.). 1951. *Virus Yellows of sugar beet and mangolds.* (J. Inst. Corn & agric. Merchants, **3,** 25-28.)

74. Hull (R.). 1951. *Spoilage of sugar beet.* (Brit. Sugar Beet Rev., **20,** 25-29.)

75. Hull (R.). 1951. *The danger of Virus Yellows.* (Fmr. & Stk.-Breed., **65,** 87.)

RESEARCH PAPERS

76. Bawden (F. C.), Chaudhuri (R. P.) and Kassanis (B.). 1951. *Some properties of broad-bean mottle virus.* (Ann. appl. Biol. **38,** 774-784.)

A severe disease affecting many plants in a crop of broad beans was found to be caused by a previously undescribed virus, provisionally named broad-bean mottle virus. The distribution of diseased plants suggested spread by a vector, but none of the six insects tested transmitted it. The virus was transmitted to several species of leguminous plants by mechanical inoculation of sap; infectivity for some hosts seemed to be increased by propagation in these hosts.

The virus has an unusual combination of properties. Its thermal inactivation point is about 95°C, whereas sap becomes non-infective within three weeks at room temperature. The infection end-point of broad-bean sap is 1/1,000, only a little higher than the precipitation titre with specific antiserum. Precipitation with antiserum occurs over a smaller range of antigen/antibody ratios than with other viruses previously studied, possibly because of its greater solubility; it is not precipitated with $(NH_4)_2SO_4$ until the salt concentration exceeds 75 per cent saturation.

A specific nucleoprotein, containing nucleic acid of the ribose type, can be isolated from infective broad-bean sap in yields up to 2 g/l. Purified preparations, made by salt precipitation and ultracentrifugation, contain uniform spherical particles approximately 17 mμ in diameter. It is suggested that much of this nucleoprotein is non-infective but may otherwise resemble infective particles.

77. Bawden (F. C.) and Kassanis (B.). 1951. *Serologically related strains of potato virus Y that are not mutually antagonistic in plants.* (Ann. appl. Biol., **38,** 402-410.)

Tobacco veinal necrosis virus is serologically related to potato viruses Y and C. It does not protect tobacco, *Nicotiana glutinosa,* or potato plants

from infection by them, and tobacco and *N. glutinosa* plants infected with either virus Y or C are still susceptible to it. There is some evidence that it does not multiply normally in potato plants infected with virus Y and that it is sometimes suppressed in such plants.

The possession of antigenic groups in common with viruses Y and C is considered to justify tobacco veinal necrosis virus as a strain of virus Y, and to be of greater taxonomic significance than failure to protect plants against other strains. A further difference from other strains is that it is more virulent towards tobacco than towards potato.

78. Bawden (F. C.) and Kleczkowski (A.). 1952. *Ultraviolet injury to higher plants counteracted by visible light.* (Nature, Lond., **169,** 90.)

The effects of irradiating leaves of *Phaseolus vulgaris* with ultraviolet depended on whether or not the leaves were exposed to visible light immediately after irradiation. When leaves were kept in darkness, the epidermal cells collapsed and died within a few days, whereas they showed little or no ill effects when exposed to visible light. Whether illuminated or not, leaves immediately after irradiation were refractory to infection with tobacco necrosis viruses; illuminated leaves regained their original susceptibility to infection within 24 hours, whereas leaves in the dark remained highly resistant.

79. Blencowe (J. W.) and Tinsley (T. W.). 1951. *The influence of density of plant population on the incidence of yellows in sugar-beet crops.* (Ann. appl. Biol., **38,** 395-401.)

The incidence of yellows virus in sugar-beet crops was reduced by increasing the density of plant population. The variations in plant population were obtained by differences in row width and singling distance. The differences in susceptibility between large- and small-topped varieties, and between early- and late-sown crops, could not be attributed solely to differences in plant size. It is suggested that close planting would increase the yields of sugar beet and reduce the losses caused by yellows virus. Roguing infected plants during the early part of the growing season did not reduce the incidence of disease.

80. Bradley (R. H. E.). 1952. *Studies on the aphid transmission of a strain of henbane mosaic virus.* (Ann. appl. Biol., **39,** 78-97).

A virus causing wilt of *Datura stramonium* was identified as a strain of henbane mosaic virus. It causes necrotic local lesions in *Nicotiana rustica,* and local lesions are demonstrable in tobacco by staining with iodine. Some of the factors affecting its transmission by *Myzus persicae* (Sulz.) were studied quantitatively using these lesions.

Infective aphids differed little in their ability to cause infection, and usually produced two or three lesions. The duration of the feeding puncture did not affect the number of infections and had little effect on the percentage of aphids becoming infective. Transmissible virus did not seem to be continually imbibed while aphids fed on infected plants and there were indications that it was acquired immediately before aphids withdrew their stylets from the leaf. Aphids became infective when allowed to make feeding punctures into epidermis stripped from infected leaves.

M. persicae transmitted during feeding punctures as brief as 5 to 10 seconds; the probability of single feeding punctures resulting in infection reached a maximum with those lasting from 20 to 30 seconds during which the stylets did not penetrate as far as the centre of the epidermal cell and little or no saliva appeared to be ejected. *M. persicae* did not transmit the virus when its stylets were artificially wetted with infective sap.

Periods of darkness before inoculation with datura wilt virus increased the susceptibility of *N. rustica* to infection by rubbing, but not to infection by aphids.

81. Broadbent (L.). 1951. *Aphid excretion.* (Proc. R. ent. Soc. Lond., **26,** 97-103.)

The excretory habits of 22 species of aphids were studied. Most species living freely on leaves or stems raised their abdomen and stayed still while

a globule of honeydew appeared ; the globule was poised on the anus for one or two seconds until flicked off by the cauda. Nymphs kicked off the globule with a back leg. Modifications of these methods by aphids living in galls and underground are described. Aphids did not excrete except when feeding ; feeding and excretion continued in darkness. . Nymphs did not excrete during ecdysis, but adults continued at their usual rate when producing young. Evaporation affected the rate of excretion. It is suggested that wax and caudal development might be related to excretory habits.

82. Broadbent (L.) and [Hollings (M.)]. 1951. *The influence of heat on some aphids.* (Ann. appl. Biol., **38**, 577-581.)

The thermal death-points of five species of aphids removed from their host plants lay between 38 and 41°C, when tested for 1 hour at 60 per cent R.H. Many aphids alive after 1 hour at high temperatures died within the next day ; no *Myzus persicae* recovered and reproduced after 1 hour above 37·5°C. Third and fourth instars and adult apterae withstood heat better than first and second instars and alatae. More aphids died at 90 per cent R.H. than at 60 per cent R.H., and more at 60 per cent than at 30 per cent R.H. Aphids kept at 15 per cent R.H. for 4 hours before being heated showed a higher mortality than those kept at 95 per cent R.H. Aphids on plants withstood temperatures higher than their thermal death-point off the plant. Presumably aphids can continue to cool themselves by evaporation while feeding ; also lower temperatures on the surface of transpiring plant tissues will aid survival.

83. Broadbent (L.), Tinsley (T. W.), [Buddin (W.) and Roberts (E. T.)]. 1951. *The spread of lettuce mosaic in the field.* (Ann. appl. Biol., **38**, 689-706.)

The epidemiology of lettuce mosaic was studied on two farms in Buckinghamshire during 1947-50. Two patterns of spread were obvious on Farm A during 1947-8 ; (1) spread within a crop from sources initiated by seed-borne virus ; and (2) spread into a crop from nearby infected old plants. The first type caused serious losses only when aphids were unusually numerous and the incidence of seed-borne infection was high ; serious losses more often resulted from the second type. Winter crops usually suffered severely, and they initiated a cycle of infection in the spring which continued from crop to crop throughout the year when aphids were sufficiently numerous. Spread from crop to crop was much reduced during 1949-50 by planting or drilling lettuce in large blocks, well separated from each other, and by omitting a winter crop. Killing the infecting aphids with an insecticide did not prevent the introduction of virus from nearby diseased crops. The insecticidal treatment of old diseased and aphid-infested crops (but before alatae are produced) is recommended.

More diseased plants occurred near hedges, woods, trees or buildings than in the open field, presumably because such barriers halted flying aphids.

Three species of aphids were common on lettuce : *Nasonovia ribis-nigri* (Mosley), which infests the heart leaves ; and *Macrosiphum euphorbiae* (Thomas) and *Myzus persicae* (Sulzer), which infest the outer leaves. *M. euphorbiae* and *M. persicae* are vectors of lettuce mosaic, but the former is less effective than *M. persicae* which, although rarely as numerous as the other two species, is the most important vector. All three species overwintered on lettuce, and migrated from the winter crops during April-May.

One obvious need to control lettuce mosaic is the production of virus-free seed. Without this, however, the disease can be ameliorated by adopting these measures whenever practicable : lettuce crops should be planted or drilled in large blocks, well separated from each other ; diseased crops and crop-remains should be destroyed as soon as possible ; winter crops should be treated with an insecticide in late November, and insecticides should be used to prevent the production of large aphid populations, especially on old crops.

84. Glynne (Mary D.). 1951. *Effects of cultural treatments on wheat and on the incidence of eyespot, lodging, take-all and weeds. Field experiments, 1945-8.* (Ann. appl. Biol., **38**, 665-688.)

An experiment was made on the fourth, fifth and sixth successive crops of winter wheat to determine the effects of various treatments on the troubles

which result from close cereal cropping. Eyespot and lodging were prevalent in the first year (1946); weeds in the second; eyespot, lodging, take-all and weeds in the third.

Spraying with H_2SO_4 reduced the incidence of eyespot, lodging and weeds, and increased yield of grain on plots which received sulphate of ammonia (by 2·7, 2·2 and 10·0 cwt./acre in successive years).

Sulphate of ammonia increased the incidence at harvest of eyespot and lodging, reduced take-all and consistently increased yield of straw. Eyespot and lodging reduced the effect of the fertilizer on yield of grain, take-all increased it.

Increase in seed rate increased the incidence of severe eyespot and of take-all; it increased lodging except when plants were dwarfed by take-all.

Weight of straw and percentage straws with severe eyespot lesions independently affected lodging, together accounting for 51 per cent of the variance in percentage area lodged at harvest and 64 per cent of that lodged 33 days earlier.

Mean yields of grain on untreated plots sown with 3-3½ bushels seed/acre fell from 36·0 to 22·5 to 11·7 cwt./acre in successive years, whereas yields of 28·4, 29·9 and 29·1 cwt./acre were obtained on sprayed plots sown with 1½-2 bushels seed/acre which received 4 cwt./acre sulphate of ammonia showing that high yields were maintained when eyespot, lodging, take-all and weeds were controlled.

By 1948 yields of grain on unsprayed plots had fallen to the level of those on similarly manured plots on the continuous wheat experiment on Broadbalk field. Spraying increased grain by amounts similar to those resulting from one year's fallow on Broadbalk; but fallow had its greatest effects on plots with low nitrogen, spraying on those with high nitrogen.

85. Gregory (P. H.) 1951. *The fungi of Hertfordshire.* (Trans. Hertfordsh. Nat. Hist. Soc. and Field Club. **23,** 137-208.)

A compilation of records of Hertfordshire fungi from various sources, including the records of the Hertfordshire Natural History Society & Field Club, the British Museum (Natural History), the Letchworth Museum, the Ministry of Agriculture & Fisheries Plant Pathology Laboratory, Cheshunt Experimental & Research Station and original records.

86. Gregory (P. H.). 1951. *Deposition of air-borne* Lycopodium *spores on cylinders.* (Ann. appl. Biol., **38,** 357-376.)

For the study of deposition of air-borne particles on plant and trap surfaces a small wind tunnel has been constructed giving turbulent or stream-line flow up to about 10 m./sec. The efficiency with which cylinders of from 0·018 to 2·0 cm. diameter, coated with glycerine jelly, catch *Lycopodium* spores at wind speeds over the range 1-10 m./sec. has been measured experimentally with a Cascade Impactor, operated iso-kinetically, as standard. Efficiency has been found to increase as wind speed increases, and as cylinder diameter decreases. Similar effects have been observed in the field. Efficiencies observed are lower than predicted by Sell and Glauert, but agree well with those predicted by Lamgmuir and Blodgett, except with the narrowest cylinders. The standard vertical sticky traps used in routine trappings of fungus spores, pollen, and crop-protectant sprays and dusts have a low trapping efficiency.

87. Gregory (P. H.) and Waller (S.). 1951. Cryptostroma corticale *and sooty bark disease of sycamore* (Acer pseudoplatanus). (Trans. Brit. mycol. Soc., **34,** 579-597.)

Sooty bark is a lethal disease of *Acer pseudoplatanus.* It is characterized by wilt, die-back, bark shedding and by the production of a thick layer of brownish black, dry phialosphores in the bark by a fungus invading the cambium and phloem of affected trees. It has spread continuously in and around Wanstead Park, Essex, since 1945. The fungus has been identified as the North American species *Coniosporium corticale* Ell. & Ev., which is now made the type of a new genus *Cryptostroma,* because of the characters of the stroma, conidiophores and conidia.

Conclusive evidence of pathogenicity is lacking, but there is strong circumstantial evidence that the fungus is an aggressive parasite. Prelimin-

ary inoculation experiments suggest that the fungus is normally spread by air-borne spores entering through wounds and broken ends of branches. The fungus appears to be a new introduction into England.

88. Hirst (J. M.). 1952. *An automatic volumetric spore trap.* (Ann. appl. Biol., **39**, 251-65).

A suction trap has been made in which the spores entering a narrow orifice, directed into the wind, are impacted on a "Vaseline"-coated microscope slide moved across the orifice at 2 mm per hour. Estimates of spore content of the air can be made, with higher and less variable efficiency than by previous traps, at different times of day and thus be more closely correlated with variations in weather.

Wind tunnel tests with spores of *Lycopodium clavatum* showed maximal and minimal efficiencies of 93·8 per cent and 62·4 per cent respectively, with a suction rate of 10·0 litres per min., in the range of wind speeds from 1·5 to 9·3 metres per sec.

89. Kassanis (B.). 1952. *Some factors affecting the transmission of leaf roll virus by aphids.* (Ann. appl. Biol., **39**, 157-67).

Datura tatula is more suitable than potato for studying the factors influencing the transmission of potato leaf roll virus by *Myzus persicae;* it is more easily infected, provides a better source of virus for feeding aphids, produces symptoms more quickly and over a longer period of the year.

Loughnane's (1943) claim that leaf roll virus is transmitted by starved aphids that feed for only five minutes on infected plants was not confirmed. The shortest infection-feeding time in which aphids became infective was two hours; such aphids did not infect healthy plants in the first two days and, when transferred to a series of healthy plants at intervals, infected only few. The ability to cause infections was increased by increasing the length of infection feeding. Aphids fed for many days on infected plants could infect healthy plants in the first 15 minutes of test feeding, and they continued to cause infections for long periods.

Aphids became infective more readily when feeding on recently infected *D. tatula*, showing only slight symptoms, than on older plants with pronounced chlorosis; similarly, young potato sprouts showing no symptoms, were better sources of virus for aphids than older plants showing severe leaf roll.

The differences in severity of symptoms shown by potato plants with leaf roll in the field mainly occur because of differences in virulence of accompanying strains of potato virus X, but isolates of leaf roll virus were found that also varied in virulence.

90. Macfarlane (I.). 1952. *Factors affecting the survival of* Plasmodiophora brassicae *Wor. in the soil and its assessment by a host test.* (Ann. appl. Biol., **39**, 239-256).

The activity of *Plasmodiophora brassicae* Wor. in the soil was measured simultaneously by counts of root hair infection on cabbage seedlings and percentage clubbing of older plants. The logarithms of the mean number of root hair infections per seedling were linearly related to the logarithms of the spore concentration in the inoculum. A high proportion of clubbed plants could be associated with very low average numbers of root hair infections on seedlings. The percentage of clubbed plants can be used for assessing quantitatively the infestation of soil by *P. brassicae* but only at lower levels of infestation than can counts of root hair infections. An effect of early application and higher levels of nutrients in increasing clubroot indicates that the nutrient status of the soil is also important, but it is not clear whether this is due to increased club growth or to a direct effect on the fungus.

Experiments on the survival of resting spores showed that, in a wet acid soil, the numbers of infections rapidly declined to a low and nearly constant level with increasing time from inoculation. This decline could be considerably delayed by alkaline or dry soil conditions or by the addition to the soil of mustard oil (allyl isothiocyanate). This fall in activity is ascribed to spontaneous germination of resting spores, germination being prevented or delayed by such conditions as alkalinity, low soil moisture or the presence of inhibitors.

In an attempt to cause biological stimulation of resting spore germination

by growing short-term catch crops in infested soil (re-infestation of the soil from diseased crucifers being prevented), there were fewer infections on test cabbage seedlings after crucifers or ryegrass had been grown than after a number of other non-crucifers. In fallow soil, a similar reduction was, however, caused by adding nutrients alone.

It was confirmed that *P. brassicae* can infect the root hairs of a number of non-crucifers and form zoosporangia and zoospores but no other stages of the fungus have been seen in those plants.

Possible improvement of the sampling design in experiments using the root hair infection count method, is briefly discussed.

91. Nixon (H. L.) and Watson (Marion A.). 1951. *Beet yellows virus.* (Nature, Lond., **168,** 523.)

Serological studies and electron microscopy suggest that sap from plants infected with beet yellows virus contains at least two kinds of specific particles. One of these is the rod which can be seen in electron micrographs. The other probably occurs in much higher concentration, but its size and shape are unknown.

92. Watson (Marion A.), Hull (R.), Hamlyn (Brenda M. G.), and Blencowe (J. W.). 1951. *The spread of beet yellows and beet mosaic viruses in the sugar-beet root crop. I. Field observations on the virus diseases of sugar beet and their vectors* Myzus persicae, *Sulz., and* Aphis fabae, *Koch.* (Ann. appl. Biol. **38,** 743-758.)

A survey of aphids and virus diseases of sugar-beet root crops in eastern England was made between 1940 and 1948. Prior to 1943 the observations were made on fertilizer experiments; from 1943 onwards they were made on commercial fields selected for position in relation to beet and mangold seed crops. The incidence of beet yellows increased with increasing numbers of *Myzus persicae,* but not of *Aphis fabae.* The relation with *M. persicae* was sufficiently close to suggest that it is the most important, possibly the only important, vector of beet yellows virus. Beet mosaic virus also increased with increasing numbers of *M. persicae,* but the relation was not close enough to exclude the possibility of other vectors.

Numbers of *A. fabae* on sugar beet were slightly, but consistently, depressed by the use of salt as a fertilizer. Other fertilizers had variable effects. Neither aphids nor virus are likely to be greatly affected by fertilizers.

Beet yellows is most prevalent in areas where seed crops are grown, but within those areas nearness to individual seed crops did not appear to increase its incidence. *M. persicae* were more numerous on sugar beet in seed-crop areas than elsewhere, and this alone might account for the prevalence of yellows. Beet mosaic virus is more closely associated with seed crops than is beet yellows. It is most prevalent near to seed crops within the seed-crop areas.

Biochemistry Department

93. Kenten (R. H.) and Mann (P. J. G.). 1951. *The action of peroxidase systems on ferrocyanide, molybdate, tungstate and vanadate.* (Biochem. J., **50,** 29-33.)

1. Plant peroxidase catalyses the oxidation of ferrocyanide by hydrogen peroxide. The system formed by peroxidase, together with a suitable phenolic substrate, is a much more effective catalyst of the reaction.

2. Under certain conditions the rate of oxidation of manganese by peroxidase systems is markedly increased by adding molybdates, tungstates or vanadates.

3. Evidence has been obtained that this effect is due to catalysis by peroxidase systems of the oxidation of molybdates, tungstates and vanadates to the corresponding peroxy compounds by hydrogen peroxide.

94. Pirie (N. W.). 1951. *The clear representation of very small masses.* (Nature, Lond., **168,** 1008.)

95. Pirie (N. W.). 1952. *Concepts out of context: the Pied Pipers of science.* (Brit. J. Philos. Sci., **2.** 269)

96. Smithies (W. R.). 1952. *Chemical composition of a sample of mycelium of* Penicillium griseofulvum *Dierckx.* (Biochem. J., **51.** 259).

97. Tracey (M. V.). 1951. *The determination of glucosamine by alkaline decomposition.* (Biochem. J., **49,** xx.)

Glucosamine may be estimated by distillation with saturated trisodium phosphate in a Markham distillation apparatus. Ammonia is liberated quantitatively and is estimated by any suitable means in the distillate.

98. Tracey (M. V.). 1951. *Cellulase and chitinase of earthworms.* (Nature, Lond., **167,** 77.)

Indications of the presence of cellulase in water extracts of seventeen species of British earthworms were obtained by a viscometric method. Some extracts were shown to produce reducing sugar from finely divided cellulose. Similar evidence was got for the presence of chitinase in twelve species (all those examined). Evidence indicating that some at least of the enzymes were produced by the worms is presented. Enzyme levels varied greatly within and between species.

99. Holden (Margaret). 1952. *The fractionation and enzymic breakdown of some phosphorus compounds in leaf tissue.* (Biochem. J.) [In the press.]

1. The phosphorus of tobacco leaf fibre and chloroplast fractions has been fractionated into acid-soluble P, lipid P, ribonucleic acid P and deoxyribonucleic acid P. The distribution in leaves of different ages has been compared.

2. Incubation of fibre and chloroplast fractions in water and salt solutions leads to the activity of ribonuclease and a phospholipid-splitting enzyme.

3. The optimum pH for the enzymic liberation of P is between 5·5 and 6.

4. NaCl, sodium azide and sodium citrate activitate the enzymic release of P.

5. Milling the fibre does not increase the rate of liberation or the total amount of P released by enzymic action.

6. Boiled fibre, acid-extracted fibre and ethanol-ether extracted fibre on incubation at pH 6 release P in organic form but no inorganic P. When incubated in the presence of dialysed sap or a fibre extract, which have ribonuclease and phosphatase activity, inorganic P is released and the total P liberated is increased.

Nematology Department

BOOKS

100. Franklin (Mary T.). 1951. *The cyst-forming species of Heterodera.* (Commonwealth Agricultural Bureaux, Farnham Royal, Bucks.)

Publication of this review, which was mentioned in the Annual Report for 1949, was delayed until December, 1951. The review deals with eight species and two varieties of the genus *Heterodera* occurring in Britain, giving for each an account of the morphology, bionomics, effects on the host plant, host range, distribution and control measures as far as known up to the end of 1948. The 21 figures illustrate the morphology of the nematodes and their effects on the crops which they attack. A bibliography of 646 references covers the literature until the end of 1948.

101. Goodey (T.). 1951. *Soil and freshwater Nematodes.* (London, Methuen & Co., Ltd.)

This work brings together information on the free-living eelworms which often occur in decaying plant tissues, soil, humus, freshwater lakes, ponds and streams. The 190 genera dealt with are arranged systematically and a description is given of the type species of each genus or of a closely related species which is illustrated by a clear text figure. In addition to morphological information, biological data, such as food habits, predatory behaviour and associations with insects, are dealt with. Nematological techniques are set out in the introductory section of the book.

METHODS

102. Goodey (T.). 1951. *Laboratory methods for work with plant and soil nematodes.* (Min. Agric. & Fish., Tech. Bull. No. 2, H.M.S.O., 2nd ed.)

Laboratory methods and techniques are described and illustrated suitable for the collection of free-living and cyst-forming eelworms, the determination of the larval contents of cysts and the killing, fixing, processing, staining and mounting of eelworms alone or within plant tissues.

RESEARCH PAPERS

103. Fenwick (D. W.) and Reid (E.). 1951. *The use of the microbalance in laboratory experiments on* Heterodera rostochiensis. (J. Helminth, **25,** 3-4.)

Replicate batches of cysts can be put up for experiments by weight. Replacing counting by weighing involves a saving of 70-80 per cent in time. The loss of precision is very slight and data are given on it. The construction of a simple capillary balance is described.

104. Franklin (Mary T.). 1952. *A disease of* scabiosa caucasica *caused by the nematode* Aphelenchoides blastophthorus *n.sp.* (Ann. appl. Biol., **39** (1), 54-60).

A species of *Aphelenchoides* which has not previously been described has caused considerable losses by destruction of the flower buds of *Scabiosa caucasica.* The nematode is fully described and illustrated and is named *A. blastophthorus,* and an account is given of the disease caused by it.

105. Goodey (J. Basil). 1951. *A new species of Hyphomycete attacking the stem eelworm* Ditylenchus dipsaci. (Trans. Brit. mycol. Soc., **34,** 270-272.)

Ditylenchus dipsaci found in diseased calceolaria was attacked by *Verticillium sphaerosporum* n. sp. with sticky spores adhering to the nematode cuticle. The fungus penetrated the nematodes, killed them, and produced fertile hyphae outside the host bearing phialides single or in small groups, from which bundles of spherical spores were produced on apical sterigmata.

106. Goodey (J. Basil). 1951. *A secondary piliferous layer on the roots of* Hippeastrum. (Nature, Lond., **167,** 822-823.)

A secondary piliferous layer, growing beneath the primary one, was found on undamaged roots of *Hippeastrum.* Most of the roots had been almost destroyed by the attacks of a new species of *Rotylenchus,* which is being described elsewhere.

107. Goodey, (T.). 1951. *Stem eelworm attack on seedlings of vetches,* Vicia villosa *Roth. and* Vicia sativa *L.* (J. Helminth., **25** (1/2), 29-32.)

Pots inoculated with the stem eelworm in dried oat straw and sown with the vetches *Vicia villosa* Roth. and *V. sativa* L. resulted in the transfer of the parasite to both. The seedlings of *V. Villosa* were rather severely injured, whereas those of *V. sativa* were not so heavily attacked. The matter of the earliest records of stem eelworm attack on vetches is discussed.

108. Peters (B. G.). 1951. *The term " Eelworm-free soil " in plant quarantine regulations.* (Nature, Lond., **167,** 368.)

109. Peters (B. G.). 1951. *Review of work on potato root eelworm.* (Rep. Rothamst. exper. Sta., 1950, 147-156.)

Entomology Department

110. Barnes (H. F.). 1951. *Worm-eating slugs.* (Country-Side, **16,** 70-74.)

A brief illustrated account of observations, weights, feeding and marking experiments on *Testacella haliotidea* and *H. scutulum.*

111. Barnes (H. F.). 1951. *Obituary Notice—Mr. G. Fox Wilson.* (Ann. appl. Biol., **38,** 311-317.)

Contains a portrait and complete list of the publications of the late Mr. G. Fox Wilson, entomologist for many years of the Royal Horticultural Society and President 1949-50 of the Association of Applied Biologists.

112. Barnes (H. F.). 1951. *Outlines of insect phenology.* (Abst. Papers read at the Symposia, IXth Internat. Congr. Ent., Amsterdam, pp. 28-29.)

A brief abstract.

113. Barnes (H. F.). 1951. *Was it a slug or a snail?* (Bedfordshire Naturalist, **5,** 24.)

Illustrated description of molluscan feeding tracks.

114. Barnes (H.F.). 1951. *Occasional insect visitors to the home.* (Bedfordshire Naturalist, **5,** 46-47.)

Short notes on a dragon-fly, the swallow bug and a snake-fly.

115. Barnes (H. F.). 1951. *The occurrence of xylophilous gall midge larvae* (Dipt., Cecidomyidae) *in the pantry.* (Ent. mon. Mag., **87,** 241.)

The larvae of *Xylodiplosis* sp. coming out of unseasoned wood used in pantry shelving in Co. Durham.

116. Barnes (H. F.). 1951. *Wheat midge reduces yield.* (Farmer & Stockbreeder, **65,** No. 3233, 51.)

An illustrated account of the two wheat blossom midges.

117. Barnes (H. F.). 1951. *A new gall midge* (Dipt., Cecidomyidae) *predaceous on the flour mite,* Tyroglyphus farinae (*Deg.*). (Bull. ent. Res., **42,** 565-566.)

The description *Trisopsis tyroglyphi* Barnes from Russia.

118. Barnes (H. F.). 1952. *The gall midges of St. John's Wort* (Hypericum *spp.*) *with descriptions of two new species.* (Bull. ent. Res., **42,** 697-705.)

An illustrated account to aid workers in the field of biological control of weeds to distinguish the different species.

119. Barnes (H. F.) and Stokes (Barbara M.). 1951. *Marking and breeding* Testacella *slugs.* (Ann. appl. Biol., **38,** 540-545.)

An illustrated account of the activity, weights, times of activity, extent of movement and marking experiments in gardens (H.F.B.), together with the description and results of a method of keeping *Testacella* in tubes in order to study their growth rate, feeding, egg-laying and hatching (B.M.S.).

120. Johnson (C. G.). 1952. *The role of population level, flight periodicity and climate in the dispersal of aphids.* (IXth Internat. Ent. Congress.) [In the press.]

121. Johnson (C. G.) and Penman (H. L.). 1951. *The relationship of aphid density to altitude.* (Nature, Lond., **168,** 337.)

Log. aphid density to log. altitude as estimated by tow nets and by suction traps show on the average an approximate linear relation. The rate at which aphids return to earth can thus be estimated from a simple extrapolation of turbulence theory known to hold near the ground.

It is estimated that aphids in the lowest 2,000 ft. of the atmosphere should return to very low altitudes or to the ground during the evening in about two hours.

122. JUDENKO (E.), JOHNSON (C. G.) and TAYLOR (L. R.). 1952. *The effect of an infestation of* Aphis fabae *Scop. on the growth and yield of field beans, in a garden plot.* (Plant Path.) [In the press.]

The effect of a measured infestation, on total yield, stem length, number of pods, etc., was assessed. Total yield (weight of beans) was reduced by 43 per cent although the infestation was very moderate and of a degree unlikely to cause much concern.

123. WILLIAMS (C. B.). 1951. *Diversity as a measurable character of an animal or plant population.* (Année biol., **27,** 129-141.)

An account is given of the new quantitative expression of Diversity that has resulted largely from work carried out at Rothamsted on the structure of animal populations. Simple methods of calculation are described and examples are given of specific and generic diversity in different types of ecological associations of both animals and plants.

124. WILLIAMS (C. B.). 1952. *Comparing the efficiency of insect traps.* (Bull. ent. Res., **42,** 513-517.)

Tests were made between three different types of light traps by having each trap in a position in a small wood, and interchanging the positions each night, so that during each three days each trap had been once in each position. The sequence was repeated five times. The actual catches of Lepidoptera were converted to a logarithmic scale and an analysis of variance indicated what differences were due to differences between locations, what to difference between nights, and what to differences between the traps. It was found that the differences between the traps were not the same for all species or for all families of Lepidoptera.

125. WILLIAMS (C. B.). 1951. *Intra-generic competition as illustrated by Moreau's records of East African bird communities.* (J. Anim. Ecol., **20,** 246-268.)

There has been considerable discussion for many years about the importance of intra-generic competition in determining the survival of two or more species in the same genus within a plant or animal association. This paper shows that extensive data on the species of birds inhabiting a number of different ecological areas in East Africa indicates that there are more congeneric groups than would be expected by chance, and not fewer, which would be the case if the competition with species of the same genus was more injurious to a species than any other advantages that might occur from the generic relationship.

126. WILLIAMS (C. B.). 1952. *Sequences of wet and fine days considered in relation to the logarithmic series.* (Quart. J. R. Met. Soc., **78,** 91-96.)

The distribution of sequences of fine days at Rothamsted during 10 years was found to fit very closely to a logarithmic series. The sequences of wet days do not fit so closely, showing a shortage of single days and an excess of spells of two or three days over the calculated—but reasons are given showing that these differences may be accounted for.

127. WILLIAMS (C. B.). 1951. *Seasonal changes in flight direction of migrant butterflies in the British Isles.* (J. Anim. Ecol., **20,** 180-190.)

There have been collected at Rothamsted, in the past 20 years, many thousands of records by field naturalists of the flight of certain butterflies, giving the date, the locality and the direction of flight. An analysis of a large number of these shows definite evidence of movements towards the north in the early summer and towards the south in the autumn in at least four species of butterflies—the Red Admiral (*Vanessa atalanta*), the Clouded Yellow (*Colias edusa*), the Pale Clouded Yellow (*Colias hyale*) and the Small Tortoiseshell (*Vanessa urticae*). In the case of the Large Cabbage-white (*Pieris brassicae*) there are two main migration seasons, at the end of May and at

the end of July, but the flights are not definitely to north and south. In this latter species most of our records are of immigrants coming in across the North Sea and the English Channel from the Continent.

128. Williams (C. B.) and Singh (B. P.). 1951. *Effect of moonlight on insect activity.* (Nature, Lond., **167,** 853.)

Insects were trapped at Rothamsted in a " Suction Trap " which by means of an electric fan filters the small insects out of a definite volume of air in a definite time. With the trap at about five feet from the ground and working during the night from sunset to sunrise from July to November, 1950, there was a statistically significant lunar cycle, with about four times as many insects caught at new moon as at full moon.

Bee Department

129. Butler (C. G.). 1951. *The importance of perfume in the discovery of food by the worker honeybee* (Apis mellifera, L.) (Proc. roy. Soc. B., **138,** 403-413.)

Worker honeybees have an inherent tendency to associate certain perfumes with food. This results in untrained scouting bees being attracted to certain kinds of flowers, such as hawthorn and wild white clover, which they have never visited before.

If the perfume of a crop of newly-opened flowers is sufficiently powerful, it sometimes attracts scouting bees from a considerable distance away. But, normally, a bee has to approach to within a few centimetres of a mouth of a flower before she can appreciate its perfume. If a bee has learned to associate a particular perfume with a particular group of flowers she will seldom enter any flower in the group unless she can smell its perfume.

When a bee is attracted towards a flower or flower-like object and approaches it closely, any attractive perfume it may possess tends to act as a stimulus to further exploration which may involve settling on the object and possibly extending her tongue and seeking food in any small crevice in or around the object.

In general, the results obtained with untrained bees support the conclusions reached by von Frisch in 1919 in his work with trained bees, and suggest that both of these categories of bees behave in a similar way when seeking food.

130. Butler (C. G.). 1951. *Beekeeping and agriculture.* (Brit. agric. Bull., **4** (16), 236-241.)

A discussion of the part played by honeybees in the pollination of fruit and seed crops, and of the way in which recent advances in bee research have made it possible for beekeepers to co-operate with fruit and seed growers more effectively than in the past.

131. Ribbands (C. R.). 1951. *The flight range of the honeybee.* (J. Anim. Ecol., **20,** 220-226.)

The gains in weight of groups of colonies sited on the edges of crops were compared with those of groups of colonies sited $\frac{3}{8}$ and $\frac{3}{4}$ mile away from the same crops.

The chief crops chosen were apple, lime and heather ; the experiments were repeated in two successive years. The effect of increased flying distance was large, and increasingly detrimental, but the magnitude of the effect varied considerably. Most of the effect was a consequence of unfavourable weather. The result illustrates a disadvantage of placing large numbers of colonies in one apiary.

132. Wykes (G. R.). 1951. *Selection of certain nectars by honeybees.* (Ann. Rep. Cent. Assoc. British Beekeepers' Assoc.)

A discussion of various factors which affect the taste perception of honeybees and their selective nectar gathering behaviour when foraging.

Insecticides and Fungicides Department

133. Elliott (M.). 1951. *The insecticidal activity of the pyrethrins and related compounds.* (Pyrethrum Post, **2**, 3 ; 18-28.)

The collected data on the relationship between the chemical structure of the pyrethrins and related compounds and their insecticidal activity are reviewed and an attempt is made to assess its significance, particularly as a guide to further work.

134. Elliott (M.). 1951. *A colorimetric reaction of the pyrethrins and related esters.* (Pyrethrum Post, **2**, 3 ; p. 24.)

Note on the possible use of the colour reaction produced with carbonyl compounds when a solution of sodium and potassium hydroxide is added to an alcoholic solution of a 2,4-dinitrophenylhydrazone. The reaction is given by the pyrethrins and related synthetic compounds and might be used in their chemical estimation.

135. Lord (K. A.) and Potter (C.). 1951. *Studies on the mechanism of insecticidal action of organo-phosphorus compounds with particular reference to their anti-esterase activity.* (Ann. appl. Biol., **38**, 495-507.)

The preparation of an extract of the mealworm larvae, *Tenebrio molitor* L. which hydrolyses ethyl butyrate and o-nitrophenyl acetate, but not acetylcholine, is described. The inhibition of this esterase by T.E.P.P.-containing materials and parathion was determined.

An enzyme that hydrolysed o-nitrophenyl acetate and was inhibited by a T.E.P.P.-containing material was demonstrated in the five other insect species used.

The relative toxicities as contact insecticides to adult *Tribolium castaneum* Hbst. of ten samples of T.E.P.P.-containing materials was compared with their relative activities as esterase inhibitors. There was not an exact quantitative correlation between T.E.P.P. content estimated chemically, insecticidal activity and anti-esterase activity ; but the correlation was sufficient to suggest interdependence of these factors.

Eggs of *Diataraxia oleracea* L. and *Ephestia kühniella* Zell. were shown to contain an enzyme that hydrolysed o-nitrophenyl acetate and was inhibited by the T.E.P.P.-containing materials. This enzyme was present in eggs less than 24 hours old, i.e. before there was any visible sign of development. The T.E.P.P. was shown to be toxic to these eggs and in high concentrations kills at an early stage of development before differentiation of the nervous system. This, in conjunction with the other evidence, suggests that esterases other than the choline-esterase of the nervous system are important when considering the toxic action of these compounds.

Comparison of the anti-esterase activity and toxicity of parathion and T.E.P.P.-containing materials as insecticides showed that although the T.E.P.P. materials were the more potent enzyme inhibitors, parathion was the more potent contact insecticide to five species of insects. This appears to be due to the relative instability of T.E.P.P. The study of the rates of action of the two poisons applied at different concentrations supports this view.

136. McIntosh (A. H.). 1951. *Particle size of insecticidal suspensions and their contact toxicity. III. Temperature coefficients and tests by injection.* (Ann. appl. Biol., **38**, 567-576.)

Aqueous D.D.T. suspensions containing particles of different sizes gave different temperature coefficients of mortality in dipping tests against adult *Oryzaephilus surinamensis* and *Tribolium castaneum*. In the range 12-30°C, colloidal D.D.T. showed a large negative coefficient, but the coefficient for a suspension of D.D.T. crystals of 400μ was smaller (*T. castaneum*) or negligible (*O. surinamensis*). Thus, although a suspension of crystalline D.D.T. was more toxic than colloidal D.D.T. to warm insects, it was less toxic than the colloid to cool insects.

A test was made of rotenone suspensions against adult milkweed bugs (*Oncopeltus fasciatus* Dall.) by application of measured droplets under the

wings. Colloidal rotenone was more toxic than a crystalline suspension. Milkweed bugs could not be killed in this way by D.D.T. suspensions.

Tests were also made by injecting suspensions of rotenone, D.D.T. and its fluorine analogue (D.F.D.T.) into milkweed bugs. A suspension of rotenone crystals was equitoxic with colloidal rotenone against insects kept for two days at 27°C after treatment. The same was true of crystalline and colloidal D.D.T. suspensions. If the bugs were kept at 10°C, colloidal rotenone was much more toxic than crystalline rotenone two days after treatment. But if the insects were kept for about three weeks and inspected at intervals, the first apparent difference in toxicity grew smaller, and in the end it nearly disappeared. With D.D.T. the time for this to occur was about 10 days; and suspensions of colloidal and crystalline D.F.D.T. were equitoxic after only two days, even at 10°C.

In the application test, the difference between colloidal and crystalline rotenone was a real difference in toxicity. It did not disappear with the lapse of time; but in the injection tests the two forms of each poison differed only in speed of action, and not in ultimate toxicity.

137. McIntosh (A. H.). 1951. *Particle size of insecticidal suspensions and their contact toxicity. IV. Mechanisms of action of different size particles.* (Ann. appl. Biol., **38**, 881-898.)

Two earlier papers showed that in tests of suspensions by dipping, large crystals of D.D.T. could kill grain beetles just as efficiently as colloidal D.D.T. But with rotenone, colloidal particles were far more toxic than large crystals; this difference was partly in their speeds of action. A third paper showed that in contact action the relative toxicity of small particles is increased by cooling the beetles after treatment. In tests by injection into milkweed bugs, particle size seemed to have no effect on toxicity of rotenone and D.D.T. suspensions if the bugs were kept warm after treatment. In cool bugs, colloid acted more quickly than crystals, but the kills from the two types finally became the same. The time for this to come about was less for D.D.T. than for rotenone and less still for D.F.D.T., an analogue of D.D.T.

An explanation of these results is now given. In the action of contact poisons, attention is given to the waxy layer on the outside of the cuticle. Contact poisons must first of all dissolve in this wax layer, and it is suggested that the difference in action between rotenone and D.D.T. is due to a difference in their solubilities in wax.

Small particles will always have the advantages, over large, of greater surface area and greater ability to enter openings in the body. With *Oryzaephilus surinamensis*, a main route of entry by rotenone into the body is possibly through the spiracles, and this may be why colloidal rotenone is so much more toxic than rotenone crystals. The solubility of rotenone in wax is thought to be small and if this is so, it will be easy to saturate the wax and the higher solubility of very small particles of rotenone will be of importance. The behaviour of rotenone particles of different sizes is therefore understandable.

Entry through the body openings is evidently unimportant for D.D.T., because large crystals kill as quickly as small ones. Penetration must be through the general cuticle. It is suggested that the solubility of D.D.T. in wax is very high, compared with rotenone; the wax will not be easily saturated by D.D.T. and small particles will not have the advantage of higher solubility which is only helpful if saturation is reached.

It is shown theoretically that if solubility (in wax) does decide the relative behaviour of different-sized poison particles, then colloidal poison should be more toxic, relative to crystalline poison, if the insects are kept cool after treatment than if they are kept warm.

The following explanation is offered for the injection results. The blood of milkweed bugs contains free droplets of oil, and these are mainly responsible for carrying poison from injected crystals to the site of action. Colloidal poison probably diffuses there directly, and more quickly, in the aqueous phase of the blood. The difference in speeds of action of colloidal and crystalline poison will depend on the ratio of dose to solubility in oil. If this is large, saturation of the blood is easy, and small particles, with their special properties, act more quickly than large. If the ratio is small, the difference in speeds of action may not be detectable.

This seemed to hold for the three poisons tested, but not by any means

exactly. The ratios for rotenone, D.D.T. and D.F.D.T. were in the expected order.

Finally, it is suggested that in contact action, the relative speeds of kill of different-size poison particles may be explained in a somewhat similar way, the solubility in cuticle wax, relative to the necessary dosage, being a controlling factor.

138. Potter (C.). 1950. *Biological methods for the assessment and study of insecticidal activity in the laboratory; their scope and validity.* (Proc. 11nd Int. Congr. Crop Protection.)

A review of methods and a discussion of the significance of the results obtained with them.

139. Potter (C.). 1951. *Insecticides and their study.* (*The Fernhurst Lecture* 1951.) (J. R. Soc. Arts, **99**, 388-407.)

A critical review with an analysis of current problems and suggestions for further work.

140. Way (M. J.), Smith (Pauline) and Hopkins (B.). 1951. *The selection and rearing of leaf eating insects for use as test subjects in the study of insecticides.* (Bull. ent. Res., **42**, 331-354.)

A number of leaf-eating insects have been studied with the object of selecting species suitable for rearing in the laboratory.

Four species have proved satisfactory for large-scale rearing throughout the year. These are *Plutella maculipennis, Plusia gamma, Diataraxia oleracea* and *Phaedon cochleariae.* A number of species possess certain disadvantages: (1) apparently obligate diapause (*Mamestra brassicae, Sphinx ligustri*). (2) The same as (1) with the additional disadvantage of lack of foodplant in winter (*Lymantria dispar*). (3) Uncertain copulation and oviposition (*Pieris brassicae*). When available, these species may be reared satisfactorily in large numbers.

Mesographe forficalis, Xanthorhöe fluctuata, Lema melanopa and *Crioceris asparagi* have been reared in relatively small numbers. They possess certain disadvantages but should be satisfactory for large scale rearing at any rate during some part of the year.

At present, laboratory rearing of *Phlogophora meticulosa, Agrotis segetum, Triphaena pronuba, Aclypea opaca* and *Athalia colibri* is considered impracticable. A number of leaf-eating species, particularly Hymenoptera, which appear to possess suitable qualities for laboratory rearing, have not yet been obtained and studied in the laboratory.

Particular attention has been paid to factors influencing development of leaf-feeding insects with the object of determining the conditions under which healthy stocks of uniform resistance can be maintained. The results of experiments on the effect of food-plant, temperature, humidity and illumination are described. Studies on the factors influencing diapause in the various species are mentioned. Descriptions are given of the rearing techniques that have been developed.

Woburn Experimental Station

141. Mann (H. H.) and Barnes (T. W.). 1951. *The competition between barley and certain weeds under controlled conditions. V. Competition with clover, considered as a weed.* (Ann. appl. Biol.) [In the press.]

Soil Survey of England and Wales

142. Heathcote (W. R.). 1951. *A soil survey on warpland in Yorkshire.* (J. Soil Sci., **2**, 144-162.)

An account is given of a soil survey of the Warpland of the Humber with a description of the soils that occur and data on their chemical and mechanical composition. The technique of warping is described and the importance of subsequent drainage is shown.

143. Osmond (D. A.). 1951. *Soil survey and soil classification.* (Sci. Hort., **10**, 160-168.)

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